FACTORS AFFECTING PERFORMANCE

OF

EUCALYPTUS AND OTHER SPECIES

by

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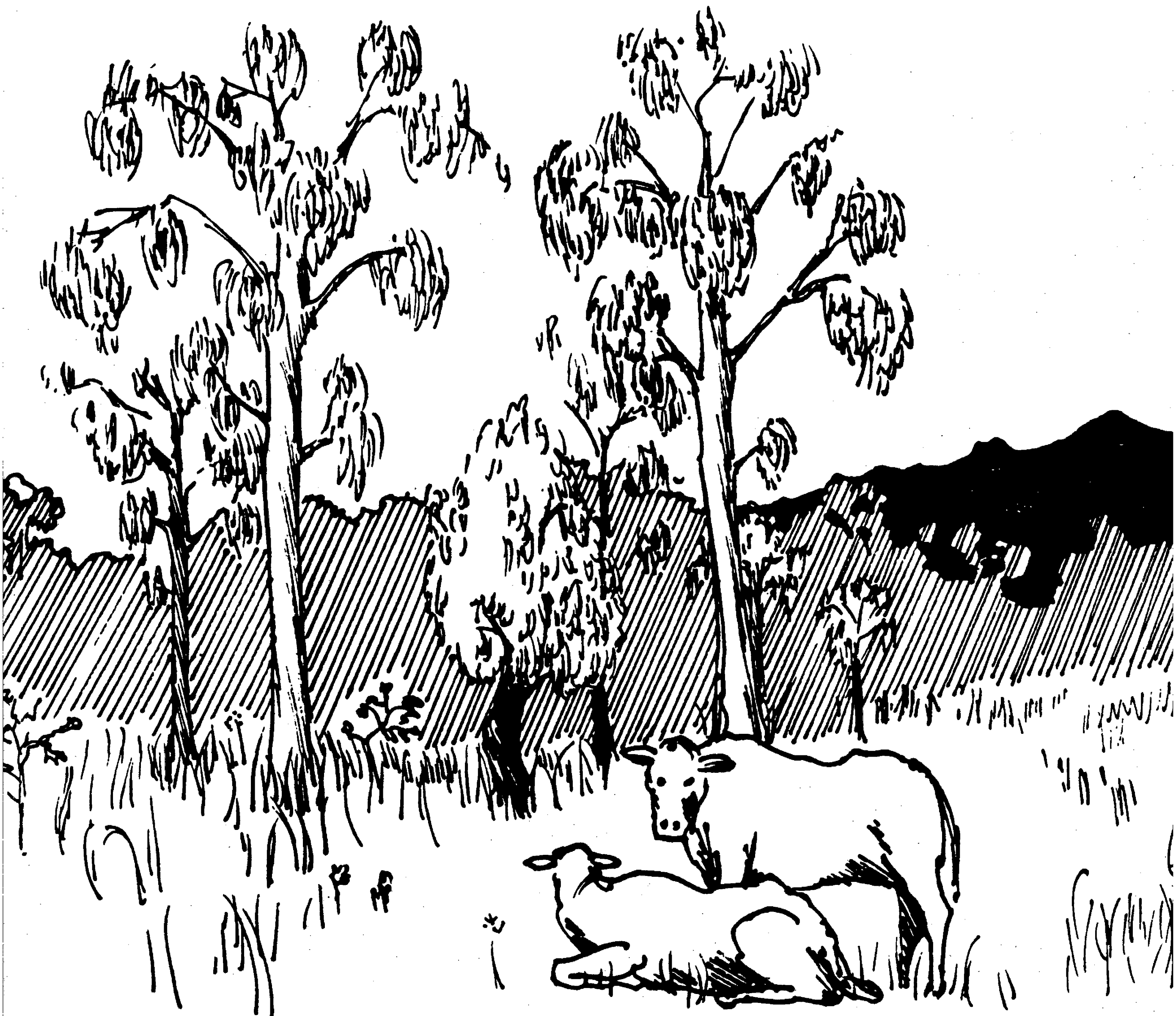

"Naturae enim non imperatur, nisi parendo."

(Nature cannot be ordered about, except by obeying her)

Francis Bacon

STATEMENT OF ORIGINALITY

Except were acknowledged, this thesis

is my own work.

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ABSTRACT

Firewood is the basic energy source for 60% of the urban population and most of the rural population of Maputo province (Mozambique). Accelerated forest degradation is further reducing the limited firewood supplies in the region. To fulfil fuel needs and exploit the existing resource in a sustainable way, plantations should be established in the area at a rate of 17000 ha/year.

Areas for forestry activities are limited to the marginal soils remaining after agriculture or livestock activities. Thus, working in such soils (mainly sandy soils with a grassy vegetation cover) the selection of appropriate species and provenances allied with the use of appropriate silvicultural techniques is essential to guarantee adequate yield.

The studies described in this thesis have examined how growth of *E.grandis* and *E.camaldulensis* is affected by different silvicultural factors, initially in the field, and later with respect to the effects of water and weed competition, in glasshouse conditions, in Canberra. They revealed that:

(i) Factors which affect performance of *Eucalyptus* were more marked in *E.grandis* (a more demanding species) and least in the *E.camaldulensis* provenance from Petford. The negative effect of weeds was strong as they reduced both survival and growth. Thus, better land preparation allied with good weed control was effective in improving performance of both species;

(ii) The effect of weeds appeared to be a result of competition for water rather than for nutrient. Possible allelopathic effects could be investigated in further studies;

(iii) Some differences among provenances of *E.camaldulensis* from different climatic regions may contribute to their successful establishment and performance in plantations: The provenance from the humid tropics (Petford) appeared to be the most suited to planting in a wide range of different environment conditions as it was the least affected by the adverse weed and low water treatments. There was evidence that it did not need to modify its root system to tolerate water stress; The three provenances from the dry tropics (Gilbert River, Manning Creek and Victoria River), had greater root:shoot ratios, yet were more affected by the stress treatments and so they may prefer areas with regular distribution of rainfall; The provenance from the temperate zone (Lake Albacutya), with the lowest root:shoot ratio, was not able to increase its root system in presence of weeds or with low water and, like the previous group, was adversely affected by such treatments.

The results have shown that detailed species and provenance trials need to be integrated with silvicultural trials. This is especially important if stress conditions are to be encountered.

LIST OF ABBREVIATIONS

A.N.U.	Australia National University
auxil.	auxiliary
camal.	camaldulensis
cu.m.	cubic meter
CSIRO	Commonwealth Scientific and Industrial Research Organisation
dbhob	diameter at breast height over bark
D.N.F.F.B.	National Directorate of Forest and Wildlife
euc.	eucalypt
Gilb. rv.	Gilbert River
grand.	grandis
ha	hectare
inhab	inhabitant
Lake Albac.	Lake Albacutya
Mann. ck.	Manning Creek
M.O.	organic matter
Mt.	mountain
N.C.Harb.	North Coffs Harbour
NSW	New South Wales
Petf.	Petford
P.N.R.	National Reforestation Programme
proven.	provenance
QLD.	Queensland
rv.	river
Vic.	Victoria
Vict.rv.	Victoria River
W. of Wand.	West of Wandecla
wgt.	weight
yr	year

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INTRODUCTION

Maputo province, the southern province of Mozambique, is also the most populated. Because of the high population density, the pressure upon the native forests for firewood is very heavy. 60% of the energy consumed by the urban population and most of the energy consumed by the rural population comes from firewood.

Due to over-exploitation of the forest resources in the past, the native forests nowadays are of low productivity. Consequently, in supplying the high demand on firewood, the resources have been rapidly depleted, especially near the urban areas.

A huge plantation programme is needed to overcome this situation and to protect native areas or to utilize them on a sustainable basis. Land is available and easy to work as it is formed mainly of coastal plains no higher than 200 m above sea level. However, the majority of the soils are sandy, the area receives low and irregular rainfall and it is covered with grassy vegetation.

Nevertheless it is already possible to identify species suitable for implementing such a programme. Trials have shown the potential of four *Eucalyptus* species; *E.camaldulensis, E.tereticornis, E.brassiana,* and *E.grandis* (although this latter needs its survival rate improved).

Even though plantations have been established to supply firewood they are still too small to fulfil the needs. In addition, several factors have limited success of those plantations. Lack of financial support, lack of managerial capability and lack of knowledge of silvicultural practices have been some of the constraints.

The present study outlines the need for the plantations and examines some of the silvicultural factors that limit successful establishment of eucalypt plantations in Maputo.

Therefore, Chapter One gives a general picture of Maputo province. Its location, climate, soils, vegetation cover and existing stock make the first part of this chapter. Then, the demand on firewood allied with the available biomass of native forest and existing plantations stresses the need for establishing new planting areas with fast growing species. Finally, the identification of suitable species and silvicultural practices are highlighted.

A field experiment was established to compare performance of the two most widely planted species - *E.grandis* and *E.camaldulensis* - with different site preparation techniques. Chapter Two deals with the results and discussion of this experiment.

Chapter Three summarizes the conclusions of the field experiment and highlights the need for more detailed examination of the effect of soil, weed competition and water on the performance of *Eucalyptus* species. As part of this study, two glasshouses experiments were established. These are detailed in Chapter Four.

General conclusions on the factors that limit performance of eucalypt plantations are given in Chapter Five. Recommendations for improve performance and for pursuing with further studies are also highlighted here.

CHAPTER 1

General description of the region

1.1. LOCALIZATION AND GENERALITIES

Maputo province - in Mozambique - has an area of 26 000 km^2 (3.3% of the country) and is situated between the parallels 24º and 26º S Latitude and the meridians 32º and 33º E Longitude. It is bounded to the north by Gaza province (Mozambique), to the south and west by South Africa and Swaziland and to the east by the Indian Ocean (Figure 1.1).

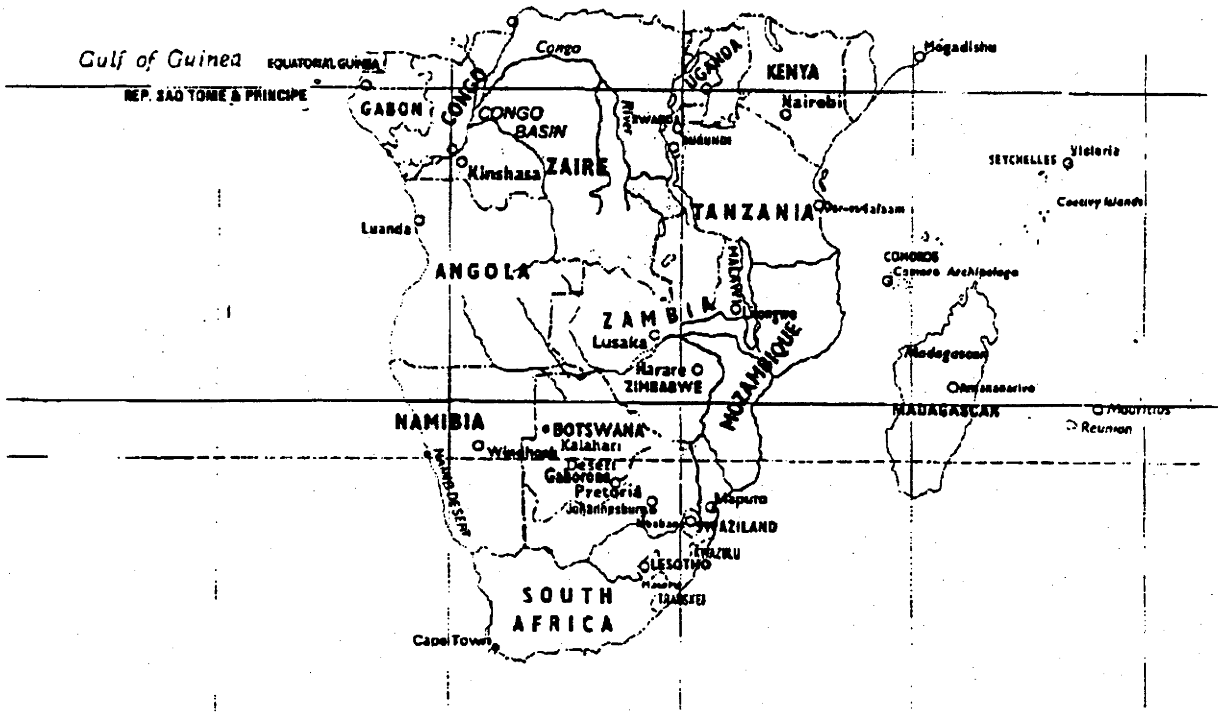
Maputo is the most densely populated province in Mozambique with 1.4 million inhabitants (10.6% of the total), on which 500 000 are rural (36%) and 900 000 are urban (64%), with a density of 20 and 1500 inhab/km^2, respectively. Population density for the country as a whole is 16.6 inhab/km^2 (CNP statistics, 1985).

The province is generally coastal plains of altitude less than 200 m. The exception is the Libombos Mountains chain, in the south-west, where the altitude is more than 500 m (the highest point is 800 m) (Figure 1.2).

There are two main rivers in the area: the Incomati river which originates in Transval Province (RSA) and the Maputo river which originates in Swaziland. Other rivers to be found in the region are the Sabié, Umbeluzi, Tembe and Matola (Figure 1.3).

The most important agriculture crops are maize, beans, cassava and sweet-potatoes. Minor crops are banana and seasonal vegetables and, sorghum, rice and sugar cane in very restricted zones. Livestock (goats, cattle and domestic animals) is also an important activity in the study area.

FIGURE 1.1: **The location of Mozambique in the south east of Africa and the studied region in the south. (Source: Anonymous, 1986)**



The area: Maputo province limited to the north by Gaza province, to the south and west by Swaziland and South Africa and to the east by the Indian Ocean.

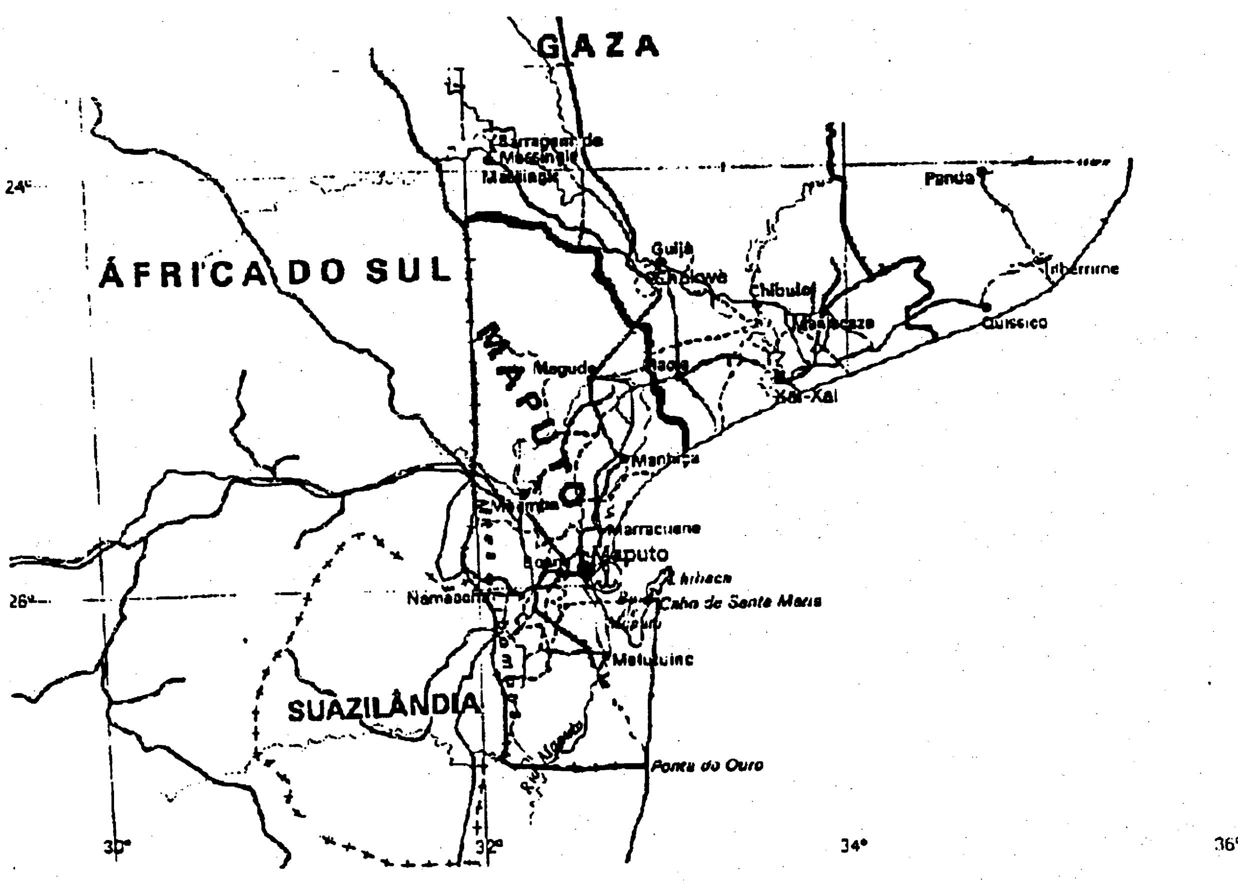


FIGURE 1.2: Hypsometric map showing the three altitude zones in the region. (Source: Reddy, 1984)

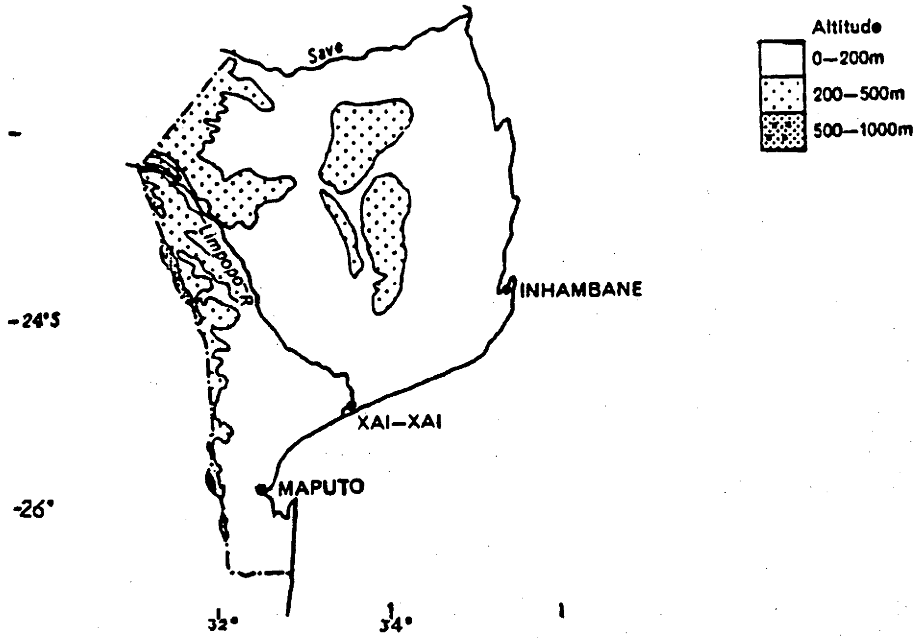
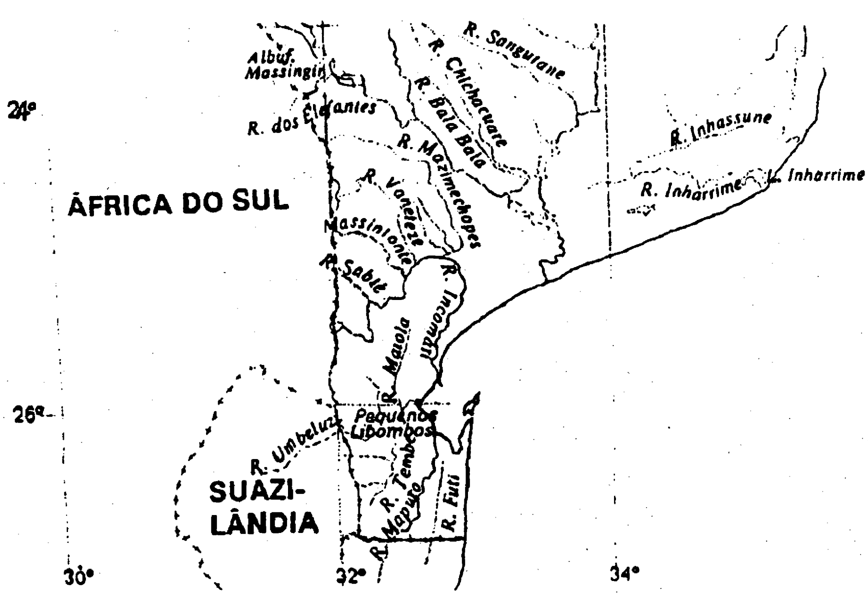


FIGURE 1.3: The main rivers that occur in the region. (Source: Anonymous, 1986)



1.1.1. Climate

The climatic zones:

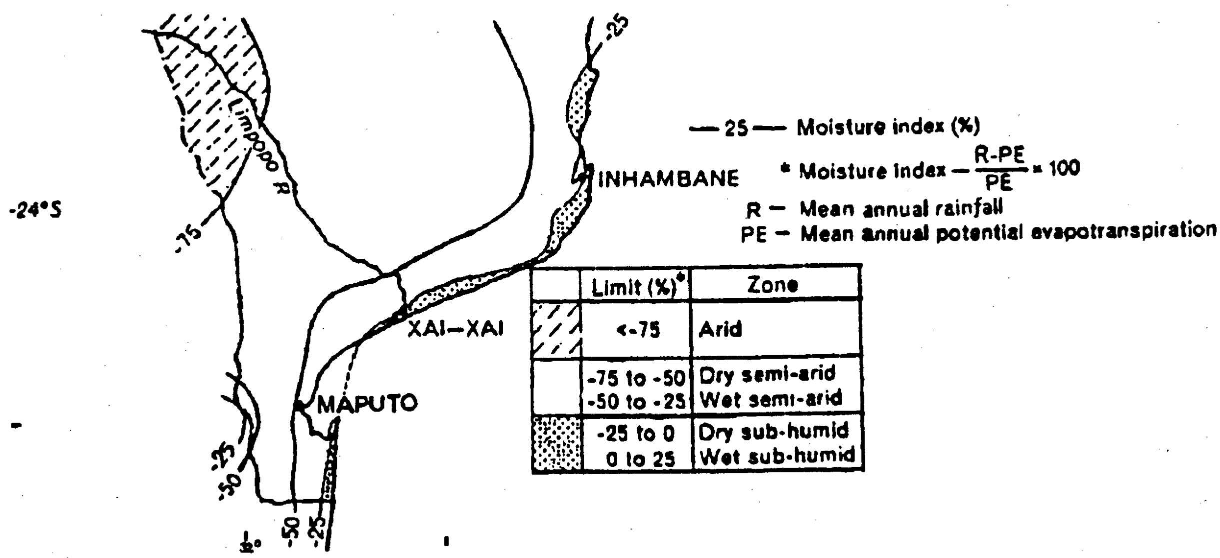
The region is subtropical having, in general, a wet and dry zone with the wet areas concentrated along the coast and in the higher altitudes of the Libombos Mountains. Reddy (1984, 1986) used a modified Thornthwaite's moisture index (which uses the mean annual values of rainfall and potential evapotranspiration), to distinguish five different climatic zones from the inland to the coast (Figure 1.4). They are:

- Arid zone: areas with a dry winter and low rainfall (< 500 mm);
- Dry semi-arid zone: with deficient rainfall all the year;
- Wet semi-arid zone: with deficient rainfall during winter;
- Dry sub-humid zone: confined to the coast, with higher rainfall (800 mm to 1000 mm);
- Wet sub-humid zone: located in the elevated areas of the Libombos Mt., without a dry season.

Temperature (ºC):

The average mean annual temperature of 23ºC to 24ºC (from coast to inland) decreases to 22ºC in the higher altitudes of the region (the Libombos Mt.) (Figure 1.5). The maximum temperatures of 27ºC to 30ºC (coast to inland) and 24ºC in the Libombos Mt. occur during summer (the wet season) from October to April. It decreases to 17ºC to 18ºC (coast to inland) and to 10ºC in the higher altitudes during winter (the dry season) from May to September.

FIGURE 1.4: **The distribution of climatic zones in the region according to a modified Thornthwaite's moisture index. (Source: Reddy, 1984).**



Rainfall (mm):

Overall the rainfall pattern shows a sea-to-inland decrease from 1000 mm to 500 mm and 900 mm in the more elevated areas (Figure 1.6). However, it can be very variable. Reddy (1984) estimated a coefficient of variation of 30%.

Other climatic characteristics:

The mean annual evapotranspiration calculated by the Penman method (FAO, 1978) varies between 1100 to 1600 mm (Figure 1.7). The highest evapotranspiration values occur during summer.

The mean annual relative humidity decreases from 75% on the coast to 65% in the inland, revealing a constant humid atmosphere throughout the year.

Table 1-Appendix I shows the means of the climatological data observed in some of the meteorological stations located in the region (Figure I.1-Appendix I) over a period of 20 to 31 years.

<u>FIGURE 1.5</u>: **The mean annual average temperature (ºC). (Source: Reddy, 1984)**

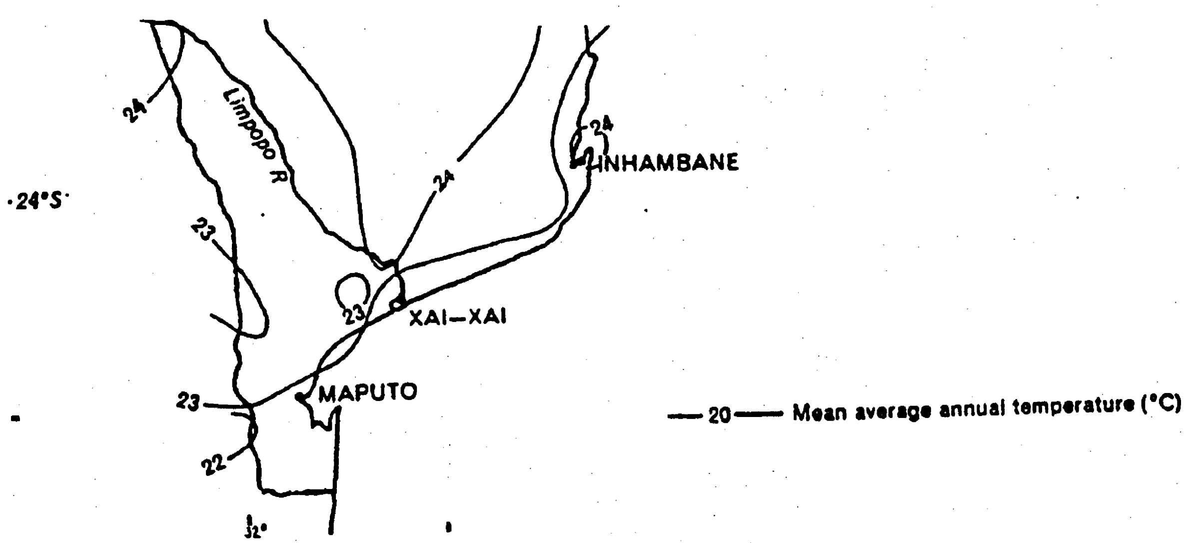


FIGURE 1.6: The lines for the mean annual rainfall (mm) and the respective coefficient of variation. (Source: Reddy, 1984)

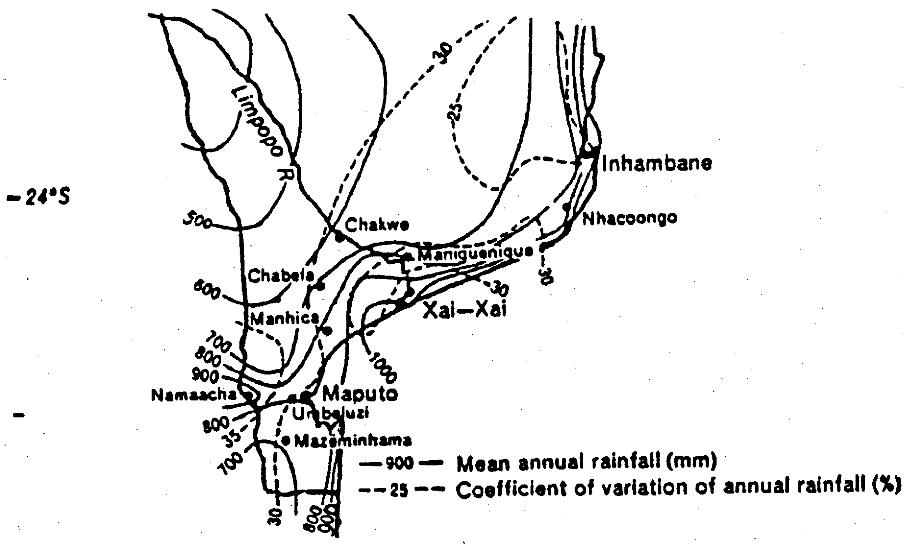
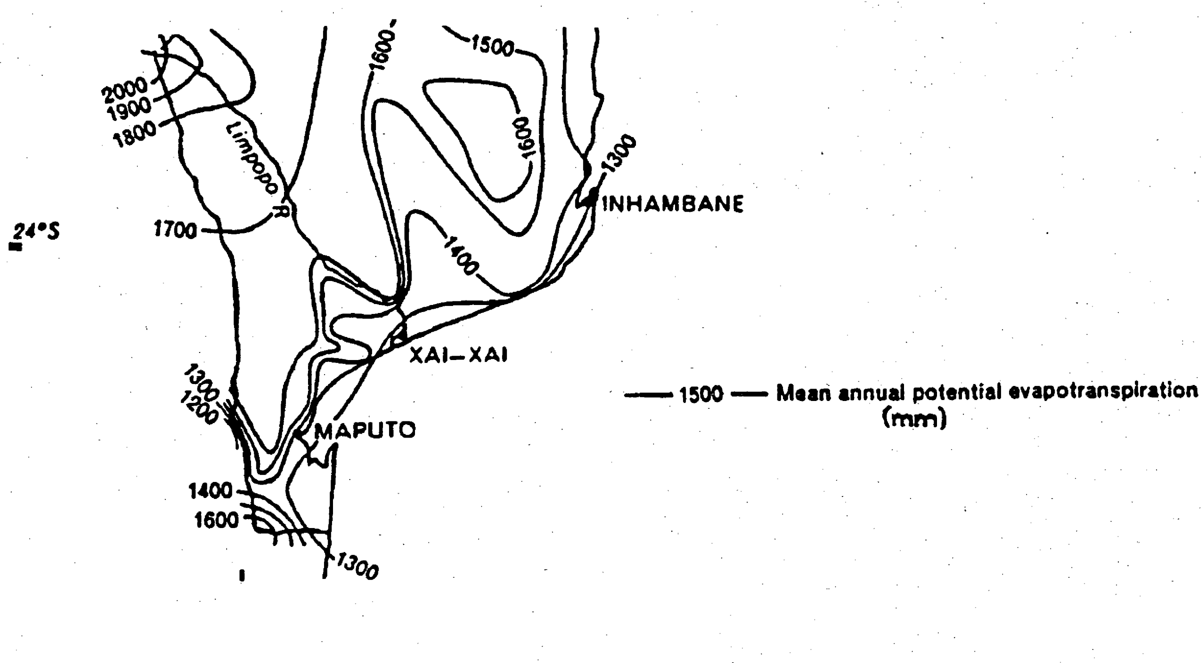


FIGURE 1.7: The mean annual potential evapotranspiration (mm). (Source: Reddy, 1984)



1.1.2. Soils

Six types of soil can be distinguished in Maputo province according to the FAO/UNESCO classification of Voortman and Spiers (1982). Figure 1.8 shows the different soils of the region.

The majority of the soils in the study area belong to the **ARENOSOLS** group. Occurring from the littoral to near the tableland of the Libombos Mt., they are poorly differentiated sands and highly weathered. The soils are formed by old dunes already fixed and alluvions from the Quartenary, with less than 15% clay and a pallid A horizon low in organic carbon. This group is subdivided into:

(i) Cambic arenosols: the major soil unit of the region. It predominates in the drier and central areas with light colours from yellow to brown and grey. These soils include sediments of calcariou~~s~~ origin and have less organic matter than the albic arenosols. They have a coarse texture with more than 65% sand, 10% of which is bleached sand. They are very well drained, with depths greater than 1 m and of low/medium fertility and pH from neutral to acid (5.5 - 7.5).

(ii) Albic arenosols: located in the south coast, originating from granites or gneiss. They have good drainage and depth~~s~~ of more than 1 m. Sometimes, the surface horizon is rich in debris from vegetation. They have a coarse texture with more than 65% sand (silty-loam sand) and a brown-light colour. They are low in fertility and acidic.

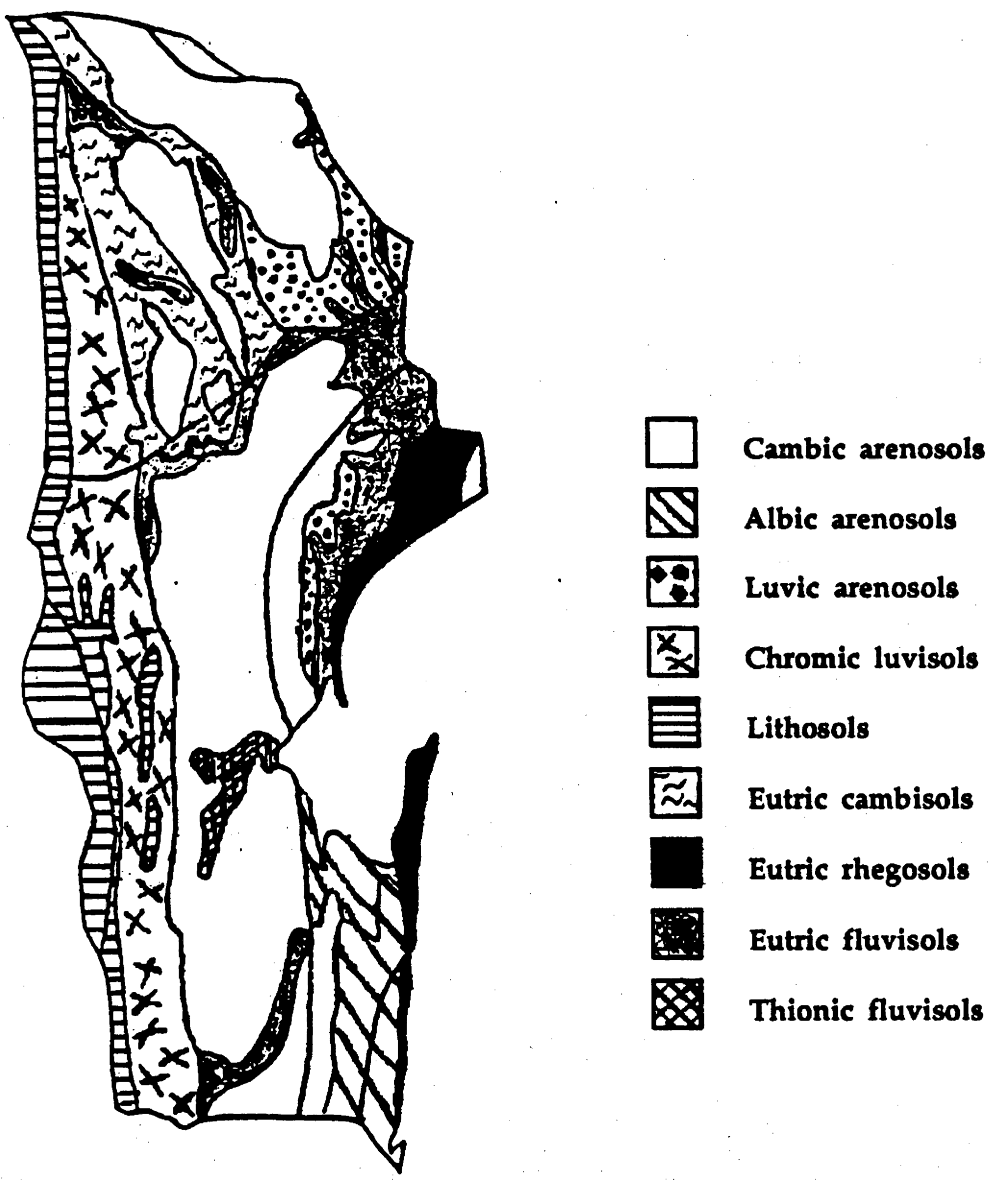
(iii) <u>Luvic arenosols:</u> occurring in small areas north of Maputo, along Incomati river and north of Incomati river, these are poorly developed soils red in colour derived from ferruginous material and coarse in texture with 65% sand (sandy-loam). Very well drained, they are deeper than 1 m with low to medium fertility (better than the first type), and pH from neutral to acid. The superficial horizon is rich in organic debris that is hardly decomposed, if at all, with approximately 0.6% O.M..

Occupying a long strip along the eastern Libombos Mountains' tableland, are the **LUVISOLS** (chromic luvisols). From the Karroo Super-Grouped and basalts Jurassic formations (from the Stormberg series) they are dark-red to black clay soils. They originated from basic eruptive rocks, with an argilluvic **B** horizon characterized by the alluvial accumulation of clay. With depths of more than 1 m, these soils have a medium/fine texture (with more than 35% clay) and are well drained. They are acidic with a medium fertility.

The **LITHOSOLS** are observed on the top and slopes of the Libombos Mt.. Derived from consolidate material of rhyolites they constitute the volcanic complex of the Libombos. With depths less than 1 m, they are stony with solid rock below the superficial horizon. The small superficial horizon has a coarse to medium texture (clay), is red to brown in colour and has a pH from acid to neutral. They have good water holding capacity.

Other soil units are observed in less extensive areas. They belong to the Cambisols, Rhegosols and Fluvisols.

FIGURE 1.8: The main soil types of Maputo province. (Adapted from Voortman and Spiers, 1982).



1.1.3. Vegetation

The forests have been classified by (i) climatic characteristics (Pedro and Barbosa, 1955; Soares and Barreto, n.d.), (ii) eco-physiological conditions and flora composition (Wild and Barbosa, 1968) and lately, (iii) by a combination of the above with the description of density levels and structure of the different tree strata (Malleux, 1980).

According to Malleux (1980), including the mangroves and the sand dunes, about 79% of the total area of Maputo province is covered with secondary forest varying from "low medium-dense forest or open forest" to "thicket", "savanna" and "grassland" formations. These can all be considered as secondary forests because of the over-exploitation that has occurred in the past, but are composed of some commercially-valuable species such as *Afzelia quanzensis, Pterocarpus angolensis, Combretum molhe, Terminalia sericea, Strychnos spp., Albizia versicolor, Acacia spp., Spirostachys africana* and *Bauhinia spp.* Other species of a socio-traditional importance for their fruits and seeds, such as *Dialium schlechteri, Strychnos innocua, Sclerocarya birrea, Strychnos spinosa and Hyphaene crinita* also occur.

The vegetation map (Figure 1.9) represents the eight vegetation zones in the region, and Figure 1.10 represents the forest types identified by Malleux (1980). Details of the vegetation zones follow:

FIGURE 1.9: The eight vegetation zones identified in Maputo province. (Source: D.N.F.F.B., 1985).

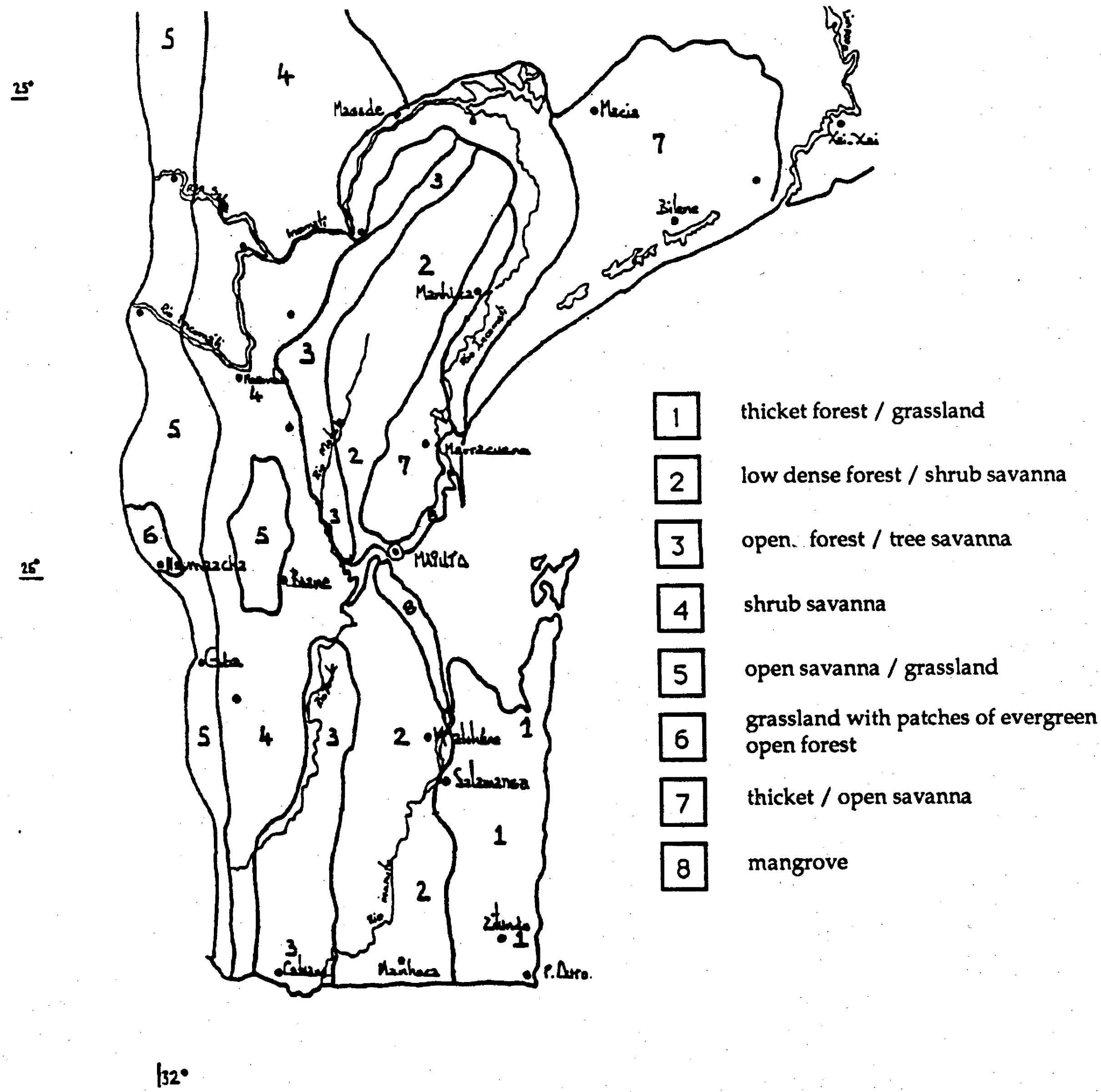
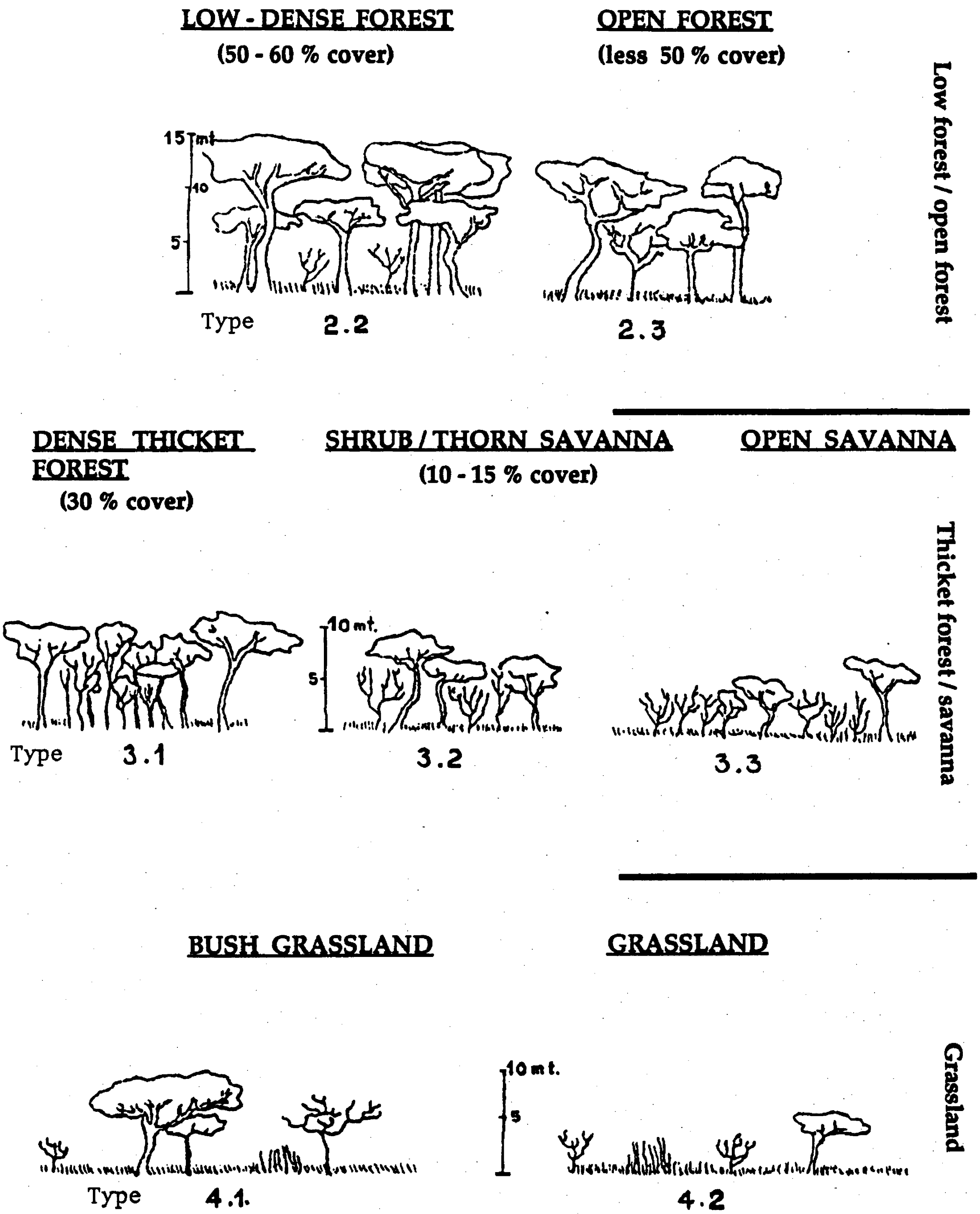


FIGURE 1.10: The different forest types (from 2.2 to 4.2) distinguished in Maputo (Source: Malleux, 1980).



Zone 1: The **south littoral zone,** also called the **coastal-savanna mosaic zone,** is mainly composed of a thicket forest; mosaics of open forest with trees on the top of the older fixed dunes and savanna with a dominant grass layer with widely scattered trees and shrubs. There are also some swamp grasslands in the temporarily flooded areas. Species common in the area are: *Sclerocarya birrea, Terminalia sericea, Albizia versicolor and A.adiantifolia, Afzelia quanzensis, Garcinia livingstonei and Strychnos spp.* They correspond to the types **3.1** to **4.2** and **2.3** locally, referred to in Figure 1.10 and Table 1.1.

Zone 2: The **central zone of Maputo and Incomati,** has patches of low medium-dense forests and open forests, and shrub-thorn savanna with scattered trees. Patches of grassland are observed in depressions. The grass layer can reach 1.5 to 3.5 m high. In addition to the species referred in the previous zone, *Combretum spp., Vangueria spp. and Syzygium cordatum* grow in depressions. Types **2.2, 2.3, 3.2,** and **3.1.**

Zone 3: The **interior zone** with a narrow and long strip of a semi-deciduous open forest with a superior strata, an intermediate strata and a well defined grass layer. *Pteleopsis myrtifolia, Spirostachys africana, Afzelia quanzensis, Balanites maughamii, Entandophragma caudatum and Euphorbia spp.* grow in mosaics of thorn-savanna with *Acacia, Spirostachys, Terminalia, Sclerocarya and Strychnos* species. Types **2.3** and **3.2.**

Zone 4 : The **Libombos plateau zone** with shrub-savanna and scattered trees, and a medium grass layer. It is composed of *Acacia spp. (A.nigrescens), Sclerocarya caffra, Combretum spp., Lonchocarpus spp. and Syzyphus mucronata.* Occasionally with mosaics of a dense thorn savanna with *Acacia and Dicrostachys species* and *Spirostachys africana.* They correspond to the types **3.2** and **3.3.**

<u>Zone 5:</u> The **slopes of the Libombos Mountains** are covered with open shrub-savanna and patches of open forest with *Pterocarpus, Combretum, Sclerocarya, Acacia, Lannea and Bauhinia* species predominantly. Types 3.3 and 4.1 and locally type 2.3.

<u>Zone 6:</u> The **high Libombos zone** with altitudes above 500 m is mainly composed of low grassland and patches of evergreen open forests on the slopes, with a predominance of *Uapaca spp.* Type 4.1.

<u>Zone 7:</u> The **Littoral north zone** with tree savanna, an intermediate shrub layer and grassland. The common species are: *Afzelia quanzensis, Sclerocarya caffra, Dialium schlechteri, Trichilia emetica, Albizia adiantifolia and A.versicolor, Garcinia livingstonei, Strychnos spp., Combretum spp., Phoenix reclinata, Guibourtia spp., Syzygium cordatum* and *Mimusops spp.* Type 3.1.

<u>Zone 8:</u> The **Mangrove zone**, found in the tidal zone and shores of Maputo river estuary and on Inhaca Island, are composed of halophyte shrubs or small trees such as: *Avicennia marina, Rhyzophora mucronata, Bruguiera cylindrica, Sonneratia alba, Heritiera littoralis* and *Lumnitzera racemosa.*

1.1.4. Existing stock

In the past, the forestry resource was much more valuable and important. It is now impoverished due to successive exploitation for logging activities, land clearing for agriculture and frequent fires. Though the forestry growing stock is composed of many different tree species only the known valuable species have been extracted. The reasons for this rest in the long traditions of the international and national markets allied with a lack of knowledge of the properties of the remaining species. Consequently, the forests nowadays can be considered as secondary composed of a few valuable species and others of minor value (Kir, 1984; Malleux, 1980; Ferreira de Castro, 1978).

The 1980 inventory of the Mozambique forestry resources by Malleux (1980) showed 79% of Maputo province to be covered with some kind of vegetation. The forest types ranged from low-medium dense forest (type 2.2), open forest (type 2.3) and thicket forest (type 3.1) - the commercial forests -, to savanna and grassland formations (from types 3.2 to 4.2) - the agroforestry potential areas (Table 1.1). Other types were mangrove and dunes vegetation.

Commercial forests cover only 24.5 % of the area (650 000 ha). The forests are classified "commercial" regarding their volume, presence and frequency of commercial and valuable species (Kir, 1984; Kalberg, 1986). This area is further subdivided into: (i) forest areas with medium potential (or medium productivity) of 120 000 ha representing a mean volume of 81.8 cu.m./ha and, (ii) forest areas with low potential (or low productivity) of 530 000 ha representing a mean volume of 50.6 cu.m./ha.

The remaining area is classified as (i) areas with forestry or agroforestry potential comprising 1.25 million ha with a mean volume of 26.2 cu.m./ha, (ii) areas with wildlife and livestock potential comprising 190 000 ha and, (iii) areas with mangroves and dunes vegetation comprising 11 000 ha.

According to Malleux's survey (1980), these commercial forests contain a total biomass of 36.5 million cu.m.. 43 % of this biomass is in trees with diameters over 25 cm dbhob but only 14% with diameters over 40 cm dbhob. The valuable species represent only a small part of the growing stock (2 million cu.m. - 5.5%) with an average volume per ha for the trees with diameters over 40 cm dbhob of approximately 1.8 cu.m./ha in the forest types 2 and 3, respectively (Kir, 1984).

TABLE 1.1: The existing stock in 1980 per forest type (Malleux, 1980).

FOREST TYPE	AREA (1000 ha)		VOLUME (1000 cu.m.)				VOLUME OF VALUABLE SPECIES (1000 cu.m.)				TOTAL VOLUME (1000 cu.m.)			
			OVER 25 cm dbhob		OVER 40 cm dbhob		OVER 25 cm dbhob		OVER 40 cm dbhob					
	AREA	% OF TOTAL	cum/ha	total	cum/ha	total	cum/ha	total	cum /ha	total	Mean cum/ha	total valuable sp.	total over 25 cm	total biomass
I. COMMERCIAL FOREST OR PRODUCTIVE FORESTS:														
Medium potentiality or medium productivity....(2.2)	119.8	4.5	29.94	3586.8	16.74	2005.5	*	*	1.82	215.6	81.8	*	5592.3	9799.6
Low potentiality or low productive............... (2.3/3.1)	527.3	20	13.15	6934	6.06	3195.4	*	*	0.82	432.4	50.6	*	10129.4	26661.7
SUB-TOTAL forests	647.1	24.5	17	10520.8	7.9	5200.9	2.1	1358	1	648	56	2006	15721.7	36.461
II. AGRO-SILVO-PASTORAL POTENTIAL														
Areas with forest and agro-forest potential .. (3.2/3.3/4.1)	1239.2	46.9	*	*	*	*	*	*	*	*	26.2	*	*	32467
Areas with wildlife and livestock potential .... (4.2)	187.6	7.1	*	*	*	*	*	*	*	*	*	*	*	*
SUB-TOTAL	1426.8	54												
III. MANGROVES AND DUNES VEGETATION	11.2	0.4												
TOTAL VEGETATION COVER	2085.1	78.9		10521		5200.9		1358		648		2006	15721.7	68.928

NOTE: Total area of Maputo province : 2635.8 x 10^3 ha.

1.2. FORESTRY PRODUCTS DEMAND

The forestry sector plays a fundamental role in Mozambique's National Development Strategy as it provides goods and public services to the population and supports agriculture and industrial development and environment protection. In 1984, the forestry sector contributed 1.3% of the total export values achieved by the country and was ranked as the eighth export product out of 19 (CNP, 1985). But the export status has been declining and the current target (DNFFB, 1990) is to increase this value to 2.6% (short term strategy) and 7.4% (long term strategy). This would re-establish the 1981 and 1975 levels, respectively.

Only a small portion of the total wood production comprises industrial roundwood (Kir, 1984). Most is utilized as firewood and small building materials. Firewood is the main source of energy for much of the urban population and also some industries (60%) as well as the rural population (Pereira and Mansur, 1988). Therefore, 80% of the total energy consumed in the country comes from firewood and of this, 81% is for domestic consumption and the remainder for industry and agriculture (18% and 1%, respectively) (GTA, 1990).

A study undertaken by the Ministry of Industry and Energy for urban Maputo (Kir, 1984) provides further details. Only 30% of the population has access to electricity and gas and only 10% uses kerosene as a source of energy. The rest of the urban population relies on charcoal and fuelwood. The industries use firewood for tobacco curing, baking, fish smoking and brick curing with an estimated consumption of about 170 000 - 560 000 cu.m./yr (Pereira *et al.*, n.d.).

The consumption of firewood is dependent on availability. In 1984, the Eduardo Mondlane University (cited by Pereira *et al.*, n.d.) in a study of four communal villages found firewood consumption varied from 0.5 to 1.3 cu.m./person/yr depending on the ease of access to firewood. One village with firewood nearby had a consumption of 0.9 cu.m./person/yr whilst another with difficult access to firewood had a consumption of only 0.5 cu.m./person/yr. The estimate was an overall need of 0.8 cu.m./person/yr but this would increase in areas with a good supply of the product. Urban firewood consumption was estimated at 0.7 cu.m./person/yr.

Maputo province with a rural population of 500 000 and an urban population of 900 000, is having its forest resources depleted by the need for firewood. Table II.1-Appendix II estimates the total firewood needs for both rural and urban population to year 2002, calculates the overall available volume (from native forests - based on the 1980's existent biomass estimated by Malleux, 1980 - and plantations) and forecasts the forest biomass balance of the province (i.e., the difference between the available volume and the needs). The result is summarized in Figures 1.11 and 1.12. Because of the low productivity of the existing forests in the region, the negative balance increases with time (Figure 1.11). The calculation estimates that in the year 2002 the biomass will have been reduced to 71% of that existing in 1980 (Figure 1.12). This reduction will be aggravated if plantations are not established from year 1992 onward.

The main problem is urban firewood consumption. If rural consumption alone is considered the balance between demand and existing growing stock would improve to 124% of that present in 1980 by the year 2002 (Table 1.2).

FIGURE 1.11: **The forecast biomass balance considering the total available volume and the total rural and urban firewood needs based on the assumptions detailed on Table II.1- Appendix II.**

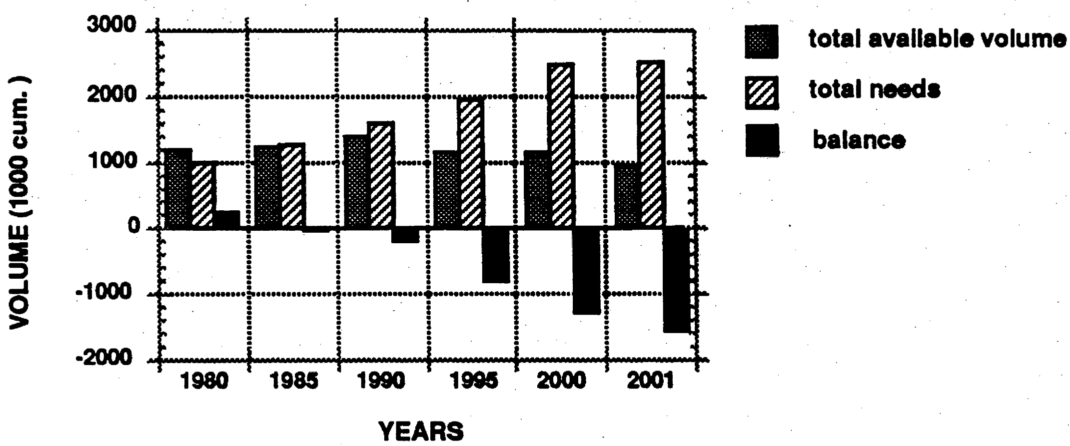


FIGURE 1.12: **The adjusted total biomass considering the initial existent stock in 1980 (Malleux, 1980), the growing stock and volume of native forests and plantations respectively and, the balance. See Table II.1 - Appendix II for detailed calculations and assumptions.**

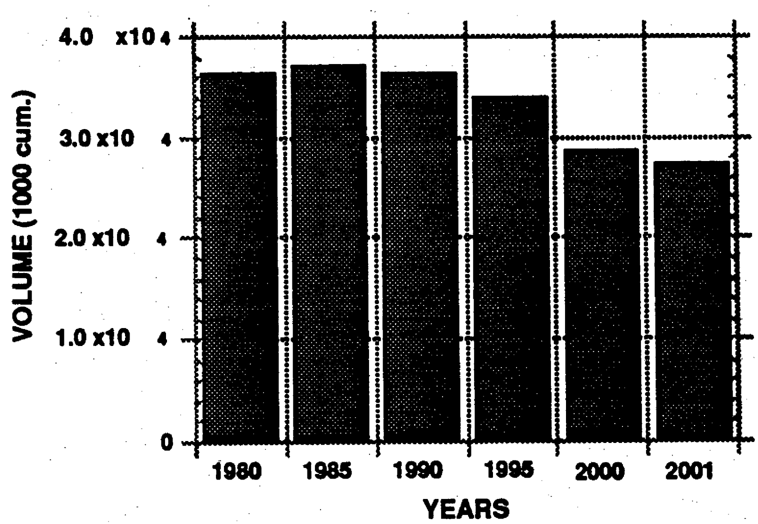


TABLE 1.2: **The forecast woodfuel biomass balance considering rural consumption alone, following the same assumptions as identified for Table II.1-Appendix II.**

YEAR	1. RURAL NEEDS (1000 cu.m.)	2. TOTAL EXISTING BIOMASS (1000 cu.m.)	3. ESTIMATED ANNUAL INCREMENT (1000 cu.m.)	4. BALANCE * 3.-1. (1000 cu.m)	5. % OF THE INITIAL BIOMASS from Col. 2
1980 †	662	36461	1203.2	541.3	100.0
1985	800	39162	1292.3	492.0	107.4
1990	917	41508	1369.8	453.2	113.8
1995	1090	43657	1440.7	350.1	119.7
2000	1333	45057	1486.9	153.7	123.6
2002	1368	45353	1496.6	128.6	124.4

* Balance is the difference between growth stock and needs.

† Initial existent biomass in 1980 (Malleux, 1980)

1.2.1. Existing plantation programmes

Because of the difficult energy situation and the resulting negative environmental effects, a big effort is being made to increase the forest area and wood volume through the establishment of plantations of fast growing species. The final objective is to supply the energy demand through the use of the resources on a renewable basis.

The Mozambique forestry policy emphasises the use of the forest resources for supply of the basic needs of the population as well as the country's economic development. The strategy is to achieve targets through:

(i) Reforestation programmes for energy purposes - using large scale plantations with fast growing species around cities, and forest extension activities in the rural areas with multi-purpose species.

(ii) Reforestation programmes for forestry industrial development.

(iii) Management of natural forestry for (i) and (ii).

According to a land use classification based on the use of the soil for agriculture (Pereira *et al.*, n.d.), the afforestation potential for Maputo province is estimated to be 15% of the total area of the province, i.e., approximately 395 000 ha. Therefore, land area is not a limiting factor for the development of afforestation programmes to fulfil the objectives above. The main constraints to the programmes are the lack of security in the rural areas, the lack of financial support, lack of known species, lack of knowledge of silvicultural practices, lack of skilled personnel and lack of experience to deal with agro-forestry schemes.

Despite the constraints, the following man-made plantations have been established in the region (PNR's annual reports):

• **4 082 ha** of eucalypt plantations for firewood purposes established around Maputo city to supply urban needs. Most of the area was planted after 1978. Only 500 ha were established before that date. Of these only 1588 ha can, at this time, be exploited.

• **1 567 ha** of plantation mainly for wood industry and poles purposes in areas near Maputo city. Of these 64% are *Eucalyptus spp.*, 14% *Pinus spp.*, 10.% *Juniperus spp.*, 6% *Casuarina spp.* and 6% others. Most of these plantations (approximately 53%) were established before 1978.

• **560 ha** established with some of the valuable native species as an experimental activity. This area was planted in the 1930's.

However, it is of importance to note that the planted area is too small to fulfil the firewood demand of the urban population. Considering rotations of 8 to 10 years and production of 12 cu.m./ha/yr in these plantations, a total production of approximately 191 000 cu.m. is estimated. This is only 27.9% of the urban needs in 1990 (Table 1.3).

The initial target was to establish a total of 25 000 ha of fast growing plantations, within a radius of 30 km from Maputo, to supply 60% of the urban needs of firewood (Pereira and Mansur, 1988). This target was not achieved due firstly to several economic and political reasons. The initial targets were set too high to supply the needs without considering the lack of expertise in both managerial and technical activities. Secondly, a very low average survival rate was obtained in the early years of the plantations. This was due to poor quality of the seedlings, low rainfall in some years, use of unsuitable species and substantial losses from fires.

The productivity of fuelwood plantations must be maximised with the choice of the right species, better cultural practices and improved fire protection. In addition, the introduction of agro-forestry schemes in rural and semi-urban areas and the training of forestry personnel is expected to increase the forest area and improve the quality and productivity of the plantations.

TABLE 1.3: **The % of the urban firewood needs to be supplied from the existing eucalypt plantations, assuming a rotation of 10 years and a production of 12 cu.m./ha/yr.**

YEAR	EXISTING PLANTATIONS AREA (ha)	EXISTING PLANTATIONS VOLUME (1000 cum)	TOTAL URBAN NEEDS (1000 cum)	% OF THE URBAN NEEDS
1990	1588	190.5	684	27.9
1991	253	30.4	719	4.2
1992	418	50.2	754	6.7
1993	331	39.7	792	5.0
1994	182	21.8	832	2.6
1995	263	31.6	873	3.6
1996	312	37.4	917	4.1
1997	410	49.2	963	5.1
1998	180	21.6	1011	2.1
1999	150	18.0	1062	1.7

1.2.2. The ideal plantation target

A total of 154 000 ha needs to be planted by the year 2000 to supply the requirements up to the year 2010. The calculations for these data are shown in Tables 1.4 and 1.5. They are based on an existing volume increment rate of native and planted forests. Of this, 110 000 ha will be needed to supply urban needs and 44 000 ha in the rural areas with difficult access to firewood. This means that the mean annual target from year 1992 to 2000 should be 12 000 ha in urban areas and 5 000 ha in rural areas, giving a total of 17 000 ha/year.

In the present situation of limited financial resources, managerial capability and technical skills, this is a highly ambitious target. However, it reflects the needs and the high priority that must be given to reforestation programmes for firewood and small building materials in the region. It should be noted that the current total annual plantation programme of the country is about 2000 ha. It is obvious that unless the country can improve plantation establishment it cannot depend on the forestry sector to solve its energy problems. Other energy sources would have to be used otherwise the vegetation cover will rapidly disappear.

TABLE 1.4: Plantation target for rural areas considering the existing volume of native and planted forests based in the 1980 initial stock (Malleux, 1980) and 3.3% annual increment for native forests and 120 cum/ha for plantations.

YEAR	RURAL NEEDS (1000 cum)	NATIVE FOREST GROSS VOLUME * (million cum)	NATIVE FOREST ANNUAL INCREMENT (million cum)	VOLUME AVAILABLE (**) FROM NATIVE FOREST (million cum)	FROM PLANTATIONS AREA (HA)	FROM PLANTATIONS VOLUME (million cum)	TOTAL (million cum)	BALANCE (***) (million cum)	NEW PLANTATION AREAS (HA)
1990	0.92	36.40	1.20	1.20	*	*	1.20	0.28	*
1991	0.93	36.20	1.19	1.19	*	*	1.19	0.26	*
1992	0.94	35.70	1.18	1.18	*	*	1.18	0.23	4307
1993	1.01	35.30	1.16	1.16	*	*	1.16	0.15	4457
1994	1.04	34.70	1.14	1.14	*	*	1.14	0.10	4624
1995	1.09	34.00	1.12	1.12	*	*	1.12	0.03	4774
1996	1.11	33.10	1.09	1.09	*	*	1.09	-0.01	4949
1997	1.17	32.20	1.06	1.06	*	*	1.06	-0.11	5132
1998	1.24	31.20	1.03	1.03	*	*	1.03	-0.21	5315
1999	1.30	30.00	0.99	0.99	*	*	0.99	-0.31	5515
2000	1.33	28.70	0.94	0.94	*	*	0.94	-0.39	5734
2001	1.35	27.40	0.90	0.90	*	*	0.90	-0.44	5974
2002	1.37	25.80	0.85	0.85	4307	0.52	1.37	0.00	1875
2003	1.39	25.80	0.85	0.85	4457	0.53	1.39	0.00	1942
2004	1.41	25.80	0.85	0.85	4624	0.55	1.41	0.00	1992
2005	1.43	25.80	0.85	0.85	4774	0.57	1.42	0.00	2067
2006	1.45	25.80	0.85	0.85	4949	0.59	1.45	0.00	2234
2007	1.47	25.80	0.85	0.85	5132	0.62	1.47	0.00	2475
2008	1.49	25.80	0.85	0.85	5315	0.64	1.49	0.00	2734
2009	1.51	25.80	0.85	0.85	5515	0.66	1.51	0.00	2994
2010	1.54	25.80	0.85	0.85	5734	0.69	1.54	0.00	3200
TOTAL NEW PLANTATIONS			FROM 1992 TO 2000						44807
			FROM 1992 TO 2010						72294

NOTES: . (*) :- Adjustable values after supply rural and urban needs . (see table 1.5).
. (**) :- Only considers the available growing stock of native forest and the existing volume of plantations.
. (***) :- Difference between total volume and needs . These values will be exported to urban areas (see table 1.5).
Negative values means extraction over increment .

TABLE 1.5: Plantation target for urban areas considering the existing volume of native and planted forests based in the 1980 initial stock (Malleux, 1980) and 3.3% annual increment for native forests and 120 cu.m./ha for plantations.

YEAR	URBAN NEEDS (million cum)	VOLUME AVAILABLE: IMPORTED NAT. FOR.(*) (million cum)	FROM PLANTATIONS: AREA (HA)	FROM PLANTATIONS: VOLUME (million cum)	TOTAL AVAIL.VOLUME (million cum)	BALANCE (**) (million cum)	NEW PLANTATION AREAS (HA)	ADJUSTED EXIST.GROSS VOLUME(***) (million cum)
1990	0.68	0.28	1588	0.19	0.47	-0.21	150	36.16
1991	0.72	0.26	253	0.03	0.29	-0.43	150	35.74
1992	0.75	0.23	418	0.05	0.28	-0.47	9824	35.27
1993	0.79	0.15	311	0.04	0.19	-0.60	10420	34.67
1994	0.83	0.1	182	0.02	0.12	-0.71	11110	33.96
1995	0.87	0.03	263	0.03	0.06	-0.81	11587	33.15
1996	0.92	-0.01	312	0.04	0.02	-0.89	12130	32.26
1997	0.96	-0.11	410	0.05	-0.06	-1.02	12657	31.23
1998	1.01	-0.21	180	0.02	-0.19	-1.20	13537	30.03
1999	1.06	-0.31	150	0.02	-0.29	-1.35	14392	28.68
2000	1.11	-0.37	1738	0.21	-0.18	-1.30	13487	27.39
2001	1.17	-0.44	403	0.05	-0.40	-1.57	15589	25.82
2002	1.23	0	10242	1.23	1.23	0.00	6542	25.82
2003	1.3	0	10751	1.3	1.29	0.00	6875	25.82
2004	1.35	0	11292	1.36	1.35	0.00	7217	25.82
2005	1.42	0	11850	1.42	1.42	0.00	7584	25.82
2006	1.5	0	12442	1.49	1.49	0.00	7958	25.82
2007	1.57	0	13067	1.57	1.57	0.00	8350	25.82
2008	1.65	0	13717	1.65	1.65	0.00	8775	25.82
2009	1.74	0	14542	1.74	1.70	0.00	9075	25.82
2010	1.83	0	15225	1.83	1.82	0.00	9567	25.82
TOTAL NEW PLANTATIONS			FROM 1992 TO 2000				109144	
			FROM 1992 TO 2010				196676	

NOTES:

. (*) :- Balance values from table 1.4.

. (**) :- Difference between total volume and needs . Negative values indicate that additional amount of biomass are extracted above increment .

. (***) :- Adjusted existing gross volume = gross volume table 1.4. + balance table 1.4.

1.3. THE PROPOSED SPECIES

1.3.1. The needs for research programmes

A lack of technical knowledge is a constraint to the development of plantations in Mozambique. This knowledge should be acquired and developed using results of applied research allied with the experience from neighbouring countries with similar conditions. Research priorities identified for firewood purposes are in the areas of:

(i) plantation and management of man-made plantation programmes and,

(ii) extension and agroforestry systems.

1.3.2. Review of research programmes

The pre - independence period:

Research conducted before independence in 1975 was poorly documented, scarce and disperse (Costa, 1983). Over 50 *Eucalyptus* species and many others exotic and native species were tested in different locations in the region. The existing records cannot be analysed in detail nor reliably, but some information has been extracted:- of the *Eucalyptus* species tested, *E.camaldulensis* and *E.saligna/E.grandis* performed well overall, the former being better in drier areas but with the latter considered superior because of its outstanding form. In addition, *E.paniculata, E.citriodora, E.maculata, E.rudis, E.creba, E.robusta* and *E.punctata* performed well in some specific locations. Approximately 26 species were eliminated because of high mortality and poor performance.

These findings were used to start the fuelwood plantation programmes in 1977. *E.grandis*, *E.saligna* and *E.camaldulensis* were selected and the majority of the seeds needed to implement the programme were collected locally with some imported, mainly from Zimbabwe (Cezerilo, 1990). The resulting plantations were very poor with a high mortality rate.

The post - independence period:

Willan (1981) produced a list of forest tree species suitable for testing in the different ecological regions of the country. Since then, eleven different species and provenance trials have been established in the region (Table 1.6). Of these, five are trials with eucalypt species suitable for firewood, five with legumes for multi-purpose uses and one to determine species suitable for flooded/saline areas.

To meet the national seed requirements and become self-sufficient in seed supply in a short period of time, an early selection was effected in the new trials. Six Seed Production Areas were established with known provenances: three with *Eucalyptus*, one with *Casuarina* and two with *Leucaena* species (Table 1.6).

Parallel studies were conducted on the existing problems of plant production, plantation and establishment. Several demonstration trials were conducted in order to give technical guidance on:

(i) nursery practices: soil mixture and fertilizer, pot size, manual watering, hardening and topping of the seedlings and plant quality.

(ii) plantation and establishment: site preparation, season, depth and pitte size of planting and weeding systems.

(iii) In addition to obtaining information on agro-forestry systems, three agroforestry demonstration trials with *Leucaena* and *Sesbania* species were established.

TABLE 1.6 **The established introduction trials and Seed Production Areas in the region since 1982. Numbers in brackets are the correspondent number of sites per each locality.**

PROGRAMME	YEAR OF ESTABLISH.	NUMBER OF TRIALS	LOCALITY
I. SPECIES INTRODUCTION TRIALS			
. Eucalypts species / provenances	1982	4 1 4	Marracuene (2) Maputo (1) Salamanga (1)
	1988	1	Moamba (1)
. Various Leguminous species	1987	1	Marracuene (1)
	1988	1	Moamba (1)
. Leguminous of Central America	1988	2 2	Matola (1) Marracuene (1)
. Leguminous of Australia	1989	1	Matola (1)
. Species for flooded / saline areas	1989	1	Mahotas (1)
II. SEED PRODUCTION AREAS			
. Euc.camaldulensis - Gilbert river (Austr.)	1986	1	Marracuene (1)
. Euc.camaldulensis -Petford (Austr.)	1987	1	Marracuene (1)
. Euc.tereticornis - Kennedy river (Austr.)	1987	1	Marracuene (1)
. Leucaena leucocephala-K 28 (Filip.)	1989	1	Marracuene (1)
. Leucaena leucocephala - K 8 (Filip.)	1989	1	Marracuene (1)
. Casuarina equisetifolia - Costa Sol (Moz.)	1989	1	Marracuene (1)

1.3.3. Summarized performance of the *Eucalyptus spp.* trials

During 1981/1982 several *Eucalyptus* species and provenances trials were established. In Maputo province, four different sites were selected: Michafutene I and Michafutene II (at Marracuene), Salamanga and Maputo city (Figure 1.13). In the first three sites, four trials were established; one with provenances of *E.camaldulensis*, one with provenances of *E.tereticornis*, one with several *Eucalyptus* species and one with *Eucalyptus* and otherspecies. In Maputo city one trial only was established, that with *Eucalyptus* species.

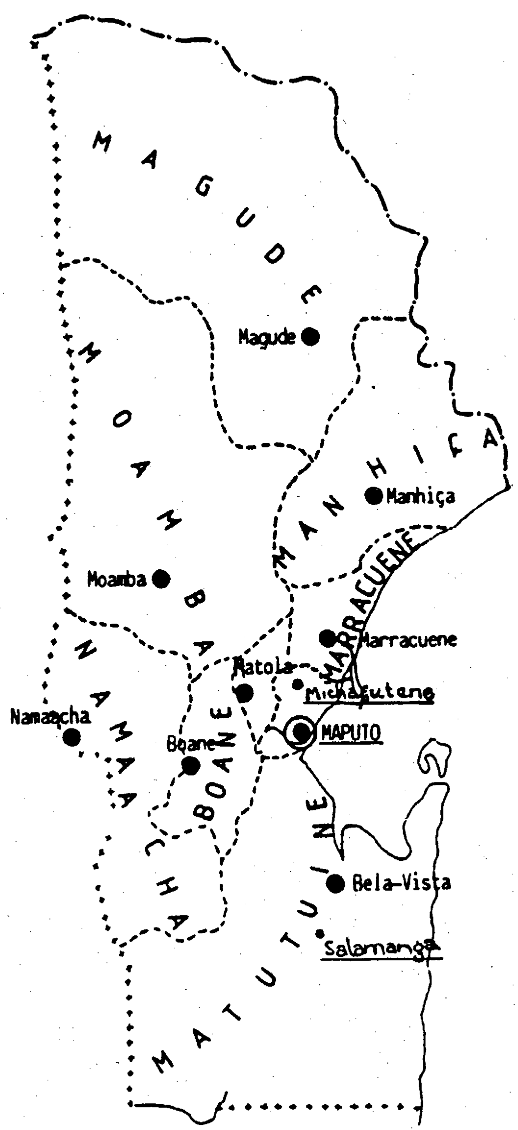
Results from one year old (for Michafutene and Salamanga), 2.5, 3.5 and seven years old (Maputo) and, three and four years old (Michafutene) were analysed by different authors: Rudin *et al* ., 1983 ; Larrobla, 1985; Pudivitr *et al.*, 1989; and Cezerilo, 1990.

With slight changes in the order of the species, similar patterns were maintained at three and four years of age on both Michafutene and Maputo trials. In both sites, *E.camaldulensis* was bigger than *E.tereticornis* though no significant differences were observed in the Maputo trial: the Zimbabwe and Petford provenances of *E.camaldulensis* were the best with the Zimbabwe provenance superior to the Petford provenance. Among the *E.tereticornis* provenances, the Kennedy River provenance was the leader followed by N.Lakeland. When provenances of *E.brassiana* were considered, the SE.Coen provenance was the best followed by Kennedy River. Other species with good growth performance included *E.grandis* (using seed from Zimbabwe and Brasil).

The findings show there is potential for eucalypts in the region. Due to the genus' characteristics of fast growing in short rotations, coppicing and high productivity, they could supply most of the requirements for firewood in a short period of time. However, there were problems of survival especially with *E.grandis*.

The next Chapter describes and analyses a field experiment established to investigate silvicultural methods to improve the performance of *E.grandis* and *E.camaldulensis* for the conditions of Maputo province.

FIGURE 1.13 : **Locations of the eucalypt trials established in the region.**



CHAPTER 2

The effect of site preparation procedures on the establishment of eucalypt plantations

2.1. OBJECTIVES

When selecting species to be planted in a specific site it is important not only to identify those which are suitable for the environmental conditions (climate and soil) but also to determine the silvicultural technologies to be applied when using such species.

The objective of this trial was to investigate the responses of two *Eucalyptus* species (***camaldulensis*** and ***grandis***) to different silvicultural techniques of land preparation, fertilizer and weeding applied during the establishment phase. Of main concern was the survival and growth of the seedlings during the first three to four years after planting.

The experiment compared performance of the species with:

- Two site preparation procedures: (i) mechanical clearing plus ploughing and, (ii) hand clearing plus pitting;
- Two weeding treatments: (i) total weeding and, (ii) partial weeding;
- One fertilizer treatment plus a control (nil fertilizer).

2.2. MATERIAL

Site description:

(a) The trial was established at Marracuene District (Maputo Province) in Michafutene (Cumbeza area). The area belongs to the FO_2 - Maputo Fuelwood Forestation Project, situated at 25.44º S Lat., 32.41º E Long. and at an altitude of 26 m. (see Figure 1.13 for location of Michafutene).

(b) The area receives a mean annual rainfall of 750 mm distributed mainly in the five months from November to March and has a mean annual temperature of 23ºC (29ºC max; 17ºC min) (Kassam *et al.*, 1981). It has a mean annual evapotranspiration of 1391 mm and a relative humidity of 70%. According to Reddy's (1984, 1986) modified Thornthwaite's moisture index the trial is situated in the wet semi-arid climatic zone.

(c) The soils are Cambic Arenosols of poorly differentiated sands of a light brown colour formed by older fixed sediments. They are coarse in texture with more than 65% of sand (10% being bleached sand). These soils are of low fertility, acidic, deep (more than 1 m) and very well drained.

(d) The trial occupies a total gross area of 1.8 ha.

The land preparation:

Both mechanical and manual land preparation were applied as part of the experimental layout (Figure 2.1). This activity was initiated in the second week of October 1987:

(i) The <u>mechanical land preparation</u> consisted of:

• Felling of trees and shrubs with the area left free of debris and stumps by using a Komatsu-D 80 with a front blade; The area was not burnt.

• To improve the soil's tilth, the area was ploughed and double-harrowed along the row using a 3 disc-harrow connected to the rear of an agricultural wheeled tractor.

(ii) The <u>manual land preparation</u> consisted of:

• Manual felling of existing trees and shrubs and stumping only the big stumps ; placing the debris into heaps and broadcast burning all the area;

• Hoeing 20 cm x 15 cm pits at planting time.

Seedling production:

Seedlings of two species of Eucalyptus, ***E.camaldulensis*** (Gilbert River provenance from QLD, Australia, lot no. 337) and ***E.grandis*** - unknown provenance (though from Zimbabwe), were produced at the Michafutene nursery. They were produced according to the normal procedures of this nursery, including direct sowing to seed-beds, pricking-out into tubes, watering, root pruning and hardening-off. Seedlings were maintained in the nursery till planting.

Establishment:

Planting was carried-out in February 1988. Each plot contained 50 seedlings planted at spacing of 3 m (between rows) and 2 m (between plants) giving a total of 5 rows with 10 seedlings each. A total of 1800 seedlings was used in the trial.

Fertilizer:

For the fertilized treatments 100 g per plant of the fertilizer N:P:K (15:30:15) was applied 15 days after planting. The fertilizer was placed within a 30 cm radius from the seedling at a depth of 10 cm and covered with a layer of soil.

Weeding:

Both the partial and total weeding treatments were applied twice a year before and after the rainy season (that is approximately in April and October each year). The weeding treatments consisted of:

(i) Partial weeding: a spot, manual, weeding within a 50 cm radius around each plant using hoes.

(ii) Total weeding: a complete mechanized weeding by ploughing inter-row and a supplementary complete hand line weeding by hoeing between plants.

The design and layout of the experiment:

A strip plot design (factorial design 3x2x2 - see Figure 2.1) was used with three replicates (blocks), three main treatments - the land preparation (strips), 2x2 subtreatments - fertilizer and species (plots), with a unit plot of 50 trees (in 5x10 seedlings). These were: (with the abbreviations used for reference shown)

(a) The main treatments were arranged in strips:

(i) MEC_TOT: mechanical land preparation with total weeding.

(ii) MEC_PAR: mechanical land preparation with partial weeding.

(iii) MAN_PAR: manual land preparation with partial weeding.

(b) The subtreatments were randomized within the strips as combinations of 2 fertilizer treatments x 2 species, where:

(i) **GR-NO:** *E.grandis* without fertilizer.

(ii) **GR-YES:** *E.grandis* with fertilizer.

(iii) **CAM-NO:** *E.camaldulensis* without fertilizer.

(iv) **CAM-YES:** *E.camaldulensis* with fertilizer.

(c) The gross plot was 5x10 seedlings. To avoid border effects, the trees used in the analyses were the central 3x8 seedlings (24).

Measurements:

Measurements were made of:

(a) survival (expressed as % of the initial stock) at six months, one year, two years, three years and four years after planting.

(b) height (in m) at six months, one year, two years, three years and four years after planting.

(c) diameter (in cm) at two years, three years and four years after planting.

(d) tree quality at three and four years after planting with the following subjective observations:

(i) **Stem form:** A - straight single stem;

B - straight single stem but slightly twisted;

C - twisted single stem with dense branches;

D - double stems or multiple leaders; or principal stem highly twisted ; or suppressed tree.

(ii) **Healthy condition:** **0** - 100% of the tree being healthy;

1 - only 50% of the tree in good healthy condition;

2 - only 25 % of the tree in good healthy condition ; or nearly dying.

The data of healthy condition of the trees was grouped into two classes: (i) healthy trees (100% healthy) and, (ii) sick trees (50% and 25% healthy or nearly dying).

(iii) **maturity stage:** **MF** - mature fruit;

IF - immature fruit;

FI - with inflorescence;

BD - with buds;

NE - neither of the above.

Because the number of trees on each of the five maturity classes was not enough to make inferences, those classes were grouped into two: (i) mature trees (for the first four stages); and (ii) immature trees (trees with neither inflorescence or fruits).

New variables:

Absolute increment values for both height and diameter were calculated and analysed. For height, the <u>Current Annual Increment</u> (CAI) was calculated at two, three and four years of age and for diameter, <u>CAI</u> was calculated at three and four years of age (as measurements started two years after planting). It was calculated as:

(i) $CAI_{(n)} = (X_{(n)}) - (X_{(n-1)})$

where: X = height or diameter (in m and cm)

n = age (years)

Problems:

During the third and fourth years, the trial was invaded by local people in search of poles to use in their buildings. This resulted in damage to many of the larger and straighter trees.

The data analysis:

The statistical package GENSTAT 5 - Release 2.2, 1990, Lawes Agricultural Trust, Rothamsted Experimental Station - (Payne *et al.*, 1987) was used for the analyses of the experiment. The structure of the analysis of variance for this experiment is detailed in Table 2.1 for the height response variable at 6 months after planting. The analysis of all the variables measured follows this structure. Details for each variable are explained in each respective section where appropriate.

FIGURE 2.1: Layout of the field experiment.

I			II			III		
GR NO	CAM YES	GR NO	GR YES	CAM NO	GR YES	CAM YES	GR NO	GR YES
CAM YES	CAM NO	CAM YES	CAM NO	GR YES	CAM NO	CAM NO	CAM YES	GR NO
GR YES	GR YES	CAM NO	GR NO	CAM YES	GR NO	GR YES	GR YES	CAM NO
CAM NO	GR NO	GR YES	CAM YES	GR NO	CAM YES	GR NO	CAM NO	CAM YES
MEC TOT	MAN PAR	MEC PAR	MEC TOT	MAN PAR	MEC PAR	MEC TOT	MAN PAR	MEC PAR

ROAD

LEGEND:

I......Block no.
MEC_TOT.....mechanical land preparation and total weeding
MAN_PAR.....manual land preparation and partial weeding
MEC_PAR.....mechanical land preparation and partial weeding
GR-NO.....*E.grandis*, no fertilizer
GR- YES.....*E.grandis*, with fertilizer
CAM-NO.....*E.camaldulensis*, no fertilizer
CAM-YES.....*E.camaldulensis*, with fertilizer

TABLE 2.1: **An example of the ANOVA for the height of the trees at 6 months after planting, showing the degrees of freedom (d.f.), sum of squares (s.s.), mean squares (m.s.), variation ratio (v.r.) and F probability (F.prob.). (numbers in brackets are missing values).**

SOURCE OF VARIATION	d.f.	s.s.	m.s.	v.r.	F prob.
block stratum	2	0.3231	0.1616	0.26	
block. strip stratum					
land preparation	2	7.7068	3.8534	6.08	0.061
Residual	4	2.5337	0.6334	4.29	
block. strip. plot stratum					
fertilizer	1	0.2188	0.2188	1.48	0.239
species	1	18.8499	18.8499	127.71	< .001
land prep. fertilizer	2	0.0035	0.0018	0.01	0.988
land prep. species	2	1.4823	0.7412	5.02	0.018
fertilizer. species	1	0.2072	0.2072	1.40	0.251
land prep. fertilizer.species	2	0.8841	0.4420	2.99	0.075
Residual	18	2.6568	0.1476	4.55	
block.strip.plot.trees stratum	645 (183)	20.9046	0.0324		
Total	680 (183)	45.5070			

2.3. RESULTS

2.3.1. Survival

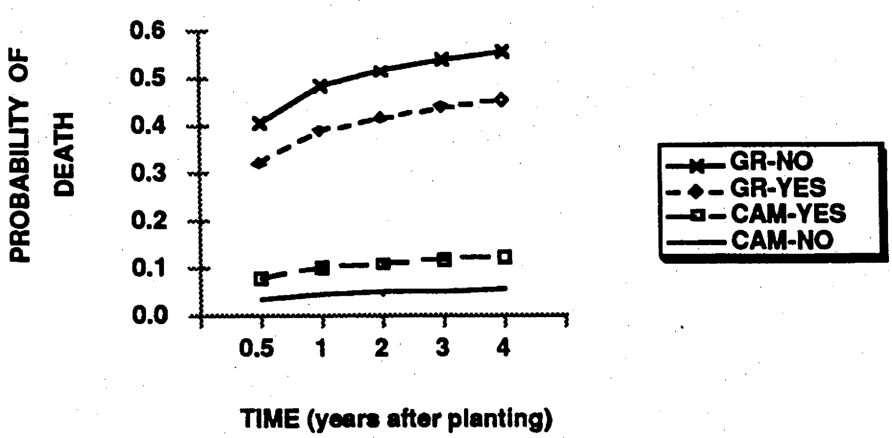
Analysis of the data:

For this analysis the percentage mortality in 24 initial trees was considered. The exploratory data analysis of the estimated probability curves for mortality over the four years (Figure 2.2) showed that the greatest occurrence of mortality happened at six months and one year after planting. After this, though some mortality still occurred, the established patterns were maintained. Thus, detailed analyses were only done for the data collected at six months and four years. A logistic regression analysis for the probability of death was used.

The accumulated analysis of deviance at six months old (Table 2.2) showed a significant species differences ($P < 0.01$), a significant effect of land preparation ($P < 0.01$) and an interaction species x fertilizer ($P < 0.01$) on the mortality of the trees. At four years old the same effects were maintained.

FIGURE 2.2: The estimated probability curves for mortality due to the effects of (i) fertilizer on trees of *E.camaldulensis* and *E.grandis* and (ii) land preparation on *Eucalyptus* trees, over four years after planting.

(i) The Species x Fertilizer interaction :



(ii) The Land preparation effect :

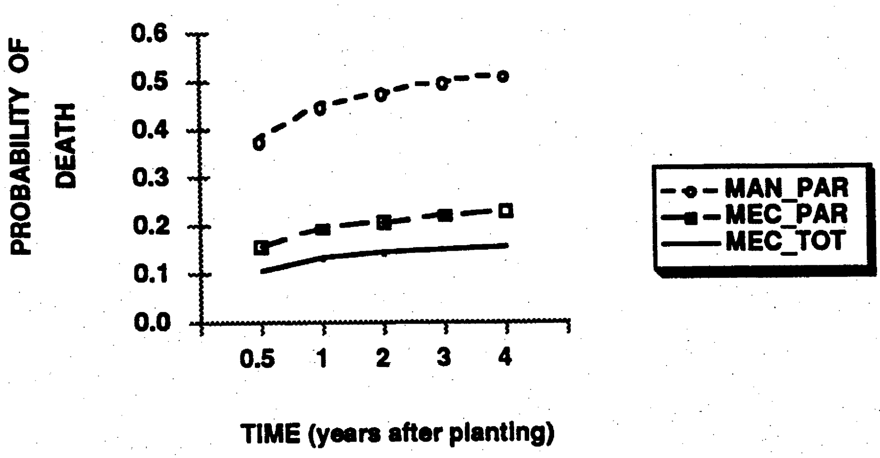


TABLE 2.2: **The accumulated analysis of deviance for mortality at six months and four years after planting.**

AGE	Change	d.f.	Deviance	Mean Deviance	Deviance ratio
6 months	Land preparation	2	101.626	50.813	65.54
	Species	1	174.900	174.900	225.60
	Species. Fertilizer	1	5.231	5.231	6.75
	Residual	18	13.955	0.775	
	Total	35	319.463	9.127	
4 years	Land preparation	2	85.373	42.687	17.78
	Species	1	218.564	218.564	91.02
	Species. Fertilizer	1	11.654	11.654	4.85
	Residual	18	43.223	2.401	
	Total	35	384.430	10.984	

Results:

The probability of mortality was significantly greater in trees of *E.grandis* than in *E.camaldulensis*. However, the application of fertilizer decreased mortality in *E.grandis* whereas it increased mortality in *E.camaldulensis* (Figure 2.2.i).

Manual site preparation with partial weeding gave much poorer results than the mechanical site preparation with both total and partial weeding. The result was evident at six months after planting and maintained to four years after planting (Figure 2.2.ii).

2.3.2. Height and diameter growth

Analysis of the data:

For various reasons (including mortality of the trees and damage by local people), the experiment had a high percentage of missing data - six months (21.2%), one year (25.6%), two years (27.3%), three years (30.6%) and four years (62.4%). Because of this, a confirmatory analysis of variance using the plot means of the existing trees was compared with the between plot analysis. As plot variance was much larger than the tree-tree variance, this between-plot analysis was considered appropriate. This was further supported by an unbalanced analysis of variance using REML - Restricted Maximal Likelihood Estimation - (Robinson, 1991).

Growth in height and diameter were analysed both overall and their current annual increment (CAI). Only the land preparation and species treatments (either alone or its interactions) affected growth. Fertilizer alone or any of the interactions involving fertilizer had no effect on either height or diameter. The resulting ANOVA are shown in Tables 2.3 to 2.6. A standard LSD ($P < 0.05$) test was used to compare means.

TABLE 2.3: **Height analysis of variance showing the degrees of freedom (d.f.), mean square (m.s.), variation ratio (V.R.) and the F probability test for the main effects and interactions, being significant at 5% level (*), 1% level (**), 0.1% level (***) and not significant (n.s.).**

AGE	SOURCE OF VARIATION	d.f.	m.s	V.R.	F prob.
6 months	land preparation	2	3.853	6.08 n.s.	0.061
	fertilizer	1	0.219	1.48 n.s.	0.239
	species	1	18.850	127.71 ***	<.001
	land prep x fertil.	2	0.002	0.01 n.s.	0.988
	land prep x species	2	0.741	5.02 **	0.018
	fertil. x species	1	0.207	1.40 n.s.	0.251
	land prep x fertil. x species	2	0.442	2.99 n.s.	0.075
1 year	land preparation	2	55.005	11.84 *	0.021
	fertilizer	1	2.443	1.76 n.s.	0.202
	species	1	15.814	11.41 **	0.004
	land prep x fertil.	2	0.056	0.04 n.s.	0.961
	land prep x species	2	6.850	4.94 *	0.02
	fertil. x species	1	4.799	3.46 n.s.	0.08
	land prep x fertil. x species	2	0.012	0.01 n.s.	0.991
2 years	land preparation	2	292.209	24.85 **	0.006
	fertilizer	1	10.166	1.92 n.s.	0.184
	species	1	16.731	3.16 n.s.	0.093
	land prep x fertil.	2	0.803	0.15 n.s.	0.86
	land prep x species	2	29.656	5.60 **	0.014
	fertil. x species	1	4.225	0.80 n.s.	0.384
	land prep x fertil. x species	2	3.083	0.58 n.s.	0.569
3 years	land preparation	2	314.596	18.24 **	0.01
	fertilizer	1	10.861	0.78 n.s.	0.389
	species	1	0.005	0.00 n.s.	0.985
	land prep x fertil.	2	1.541	0.11 n.s.	0.896
	land prep x species	2	37.070	2.67 n.s.	0.098
	fertil. x species	1	4.313	0.31 n.s.	0.585
	land prep x fertil. x species	2	7.034	0.51 n.s.	0.612
4 years	land preparation	2	386.051	9.01 *	0.033
	fertilizer	1	3.018	0.13 n.s.	0.725
	species	1	10.629	0.45 n.s.	0.511
	land prep x fertil.	2	4.037	0.17 n.s.	0.844
	land prep x species	2	26.549	1.13 n.s.	0.347
	fertil. x species	1	2.472	0.10 n.s.	0.75
	land prep x fertil. x species	2	73.148	3.10 n.s.	0.071

TABLE 2.4: **Diameter analysis of variance showing the degrees of freedom (d.f.), the mean square (m.s.), the variation ratio (V.R.) and the F probability for the main effects and interactions, being significant at 5% level (*), 1% level (**), 0.1% level (***) and not significant (n.s.).**

AGE	SOURCE OF VARIATION	d.f.	m.s	V.R.		F prob.
2 years	land preparation	2	357.734	33.45	**	0.003
	fertilizer	1	9.375	1.14	n.s.	0.301
	species	1	40.226	4.88	*	0.041
	land prep x fertil.	2	0.658	0.08	n.s.	0.924
	land prep x species	2	12.627	1.53	n.s.	0.245
	fertil. x species	1	6.609	0.8	n.s.	0.383
	land prep x fertil. x species	2	3.367	0.41	n.s.	0.671
3 years	land preparation	2	439.979	28.61	**	0.004
	fertilizer	1	7.391	0.4	n.s.	0.535
	species	1	283.468	15.35	***	0.001
	land prep x fertil.	2	3.902	0.21	n.s.	0.812
	land prep x species	2	15.175	0.82	n.s.	0.456
	fertil. x species	1	13.093	0.71	n.s.	0.411
	land prep x fertil. x species	2	18.309	0.99	n.s.	0.392
4 years	land preparation	2	514.889	8.30	*	0.038
	fertilizer	1	7.256	0.17	n.s.	0.687
	species	1	759.065	17.59	***	<.001
	land prep x fertil.	2	16.667	0.39	n.s.	0.685
	land prep x species	2	56.253	1.3	n.s.	0.297
	fertil. x species	1	19.163	0.44	n.s.	0.514
	land prep x fertil. x species	2	47.220	1.09	n.s.	0.357

TABLE 2.5: **Height increment analysis of variance showing the main effects and interactions, being significant at 5% level (*), 1% level (**), 0.1% level (***) and not significant (n.s.).**

AGE	SOURCE OF VARIATION	d.f.	m.s	VR	F prob.
CAI 1	land preparation	2	91.651	27.41 **	0.005
	fertilizer	1	2.624	1.18 n.s.	0.292
(Year 2 - Year 1)	species	1	0.320	0.14 n.s.	0.709
	land prep x fertil.	2	1.431	0.64 n.s.	0.538
	land prep x species	2	8.267	3.72 *	0.046
	fertil. x species	1	0.055	0.02 n.s.	0.877
	land prep x fertil. x species	2	2.648	1.19 n.s.	0.328
CAI 2	land preparation	2	7.033	3.28 n.s.	0.144
	fertilizer	1	0.009	0.00 n.s.	0.96
(Year 3 - Year 2)	species	1	12.390	3.72 n.s.	0.071
	land prep x fertil.	2	0.682	0.20 n.s.	0.817
	land prep x species	2	2.767	0.83 n.s.	0.453
	fertil. x species	1	0.105	0.03 n.s.	0.861
	land prep x fertil. x species	2	0.885	0.27 n.s.	0.77
CAI 3	land preparation	2	7.498	0.74 n.s.	0.534
	fertilizer	1	0.015	0.00 n.s.	0.974
(Year 4 - Year 3)	species	1	14.846	1.12 n.s.	0.304
	land prep x fertil.	2	0.914	0.07 n.s.	0.933
	land prep x species	2	9.020	0.68 n.s.	0.518
	fertil. x species	1	1.042	0.08 n.s.	0.782
	land prep x fertil. x species	2	43.049	3.26 n.s.	0.063

CAI is the current annual increment

TABLE 2.6: **Diameter increment analysis of variance showing the degrees of freedom (d.f.), mean square (m.s.) variation ratio (V.R.) and F probability for the main effects and interactions, being significant at 5% level (*), 1% level (**), 0.1% level (***) and not significant (n.s.).**

AGE	SOURCE OF VARIATION	d.f.	m.s	V.R.	F prob.
CAI 1	land preparation	2	13.533	0.45 n.s.	0.669
	fertilizer	1	1.070	0.21 n.s.	0.653
(Year 3 -	species	1	171.631	33.67 ***	<.001
Year 2)	land prep x fertil.	2	5.888	1.16 n.s.	0.339
	land prep x species	2	7.194	1.41 n.s.	0.271
	fertil. x species	1	0.172	0.03 n.s.	0.856
	land prep x fertil. x species	2	2.883	0.56 n.s.	0.584
CAI 2	land preparation	2	43.285	12.42 *	0.019
	fertilizer	1	2.961	0.22 n.s.	0.643
(Year 4 -	species	1	144.229	10.83 **	0.004
Year 3)	land prep x fertil.	2	4.651	0.35 n.s.	0.71
	land prep x species	2	4.371	0.33 n.s.	0.725
	fertil. x species	1	0.001	0.00 n.s.	0.992
	land prep x fertil. x species	2	12.943	0.97 n.s.	0.399

† CAI is the current annual increment.

Results:

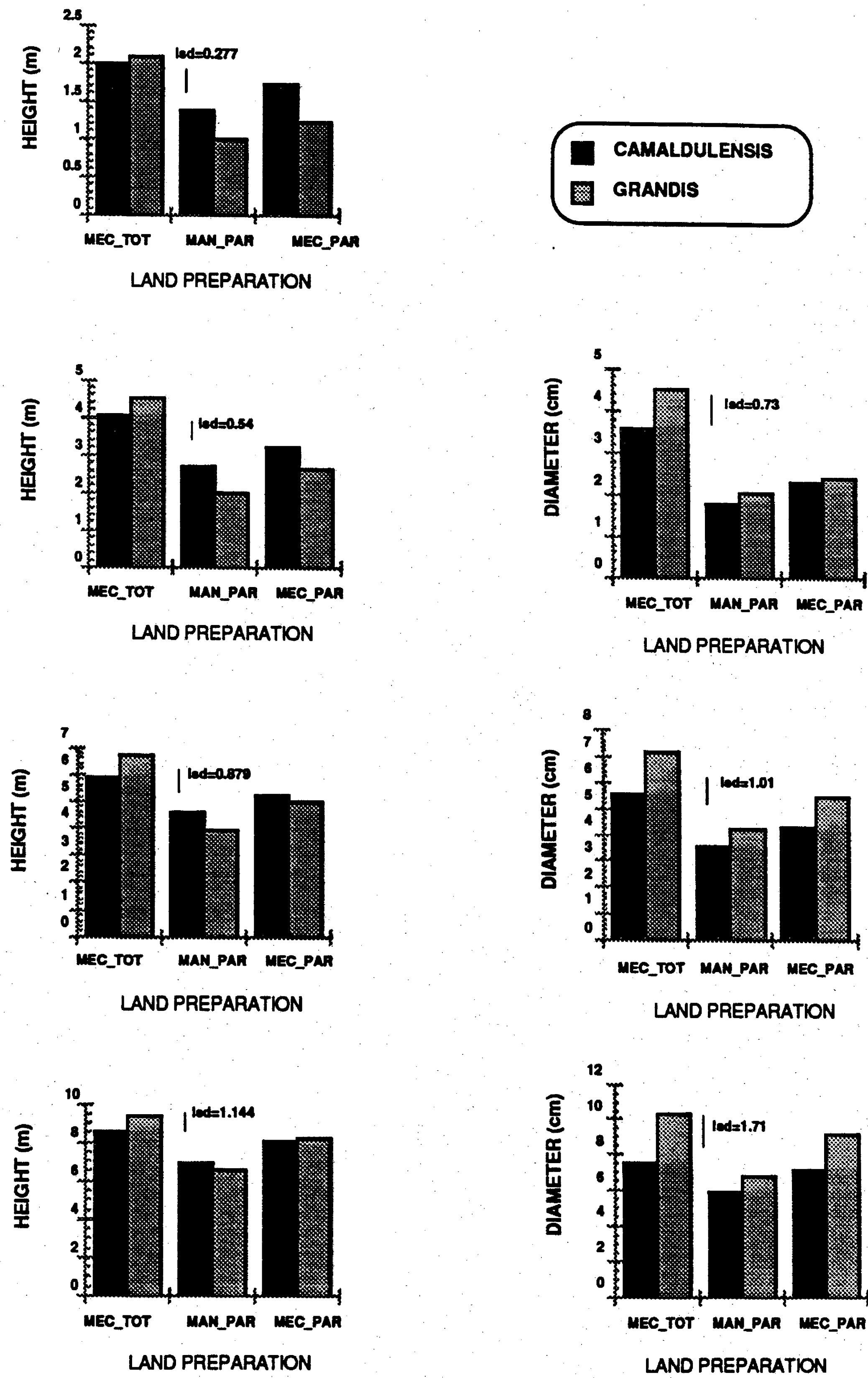
The ANOVA showed a consistent and significant land preparation x species interaction (P<0.05) on the overall height growth (during the first three years after planting) and on the current annual increment (CAI) during the second year. Thereafter, only the land preparation affected both absolute height growth and CAI as well. For diameter growth, a consistent and significant main effect of land preparation and species (P <0.05) was observed for both absolute growth and increment (CAI).

At age four years, both species had greater height and diameter growth on the mechanically prepared sites compared to the manually prepared sites. However they performed differently with the weeding procedures. On the total weeding treatments growth of *E.grandis* was slightly superior to *E.camaldulensis*. But, on the partial weeded plots, the reverse occurred during the first two years of planting (Figure 2.3).

Additionally, the two species were different in the degree of response to the site preparation treatments (Figure 2.3.). Height and diameter of *E.grandis* were respectively 26% and 34% greater on the mechanically prepared plots than on those manually prepared, whereas the corresponding figures for *E.camaldulensis* were 17% and 23% respectively. Similarly, in the weeding comparison, both height and diameter growth of *E.grandis* were 14% greater in the total weeding treatments compared to the partial weeding treatments whilst for *E.camaldulensis* they were only 6% greater.

When increment is considered, the initial height increment of both species was greater on the total weeding treatments. However, the effects had disappeared after the second year with a tendency to greater increment on the partially weeded plots (Figure 2.4). The diameter CAI of *E.grandis* was larger than that of *E.camaldulensis* and here too both species had greater increment on the partial weeded plots (Figure 2.5).

FIGURE 2.3: **The height and diameter absolute growth of the two species on the three site preparation procedures.**



<u>FIGURE 2.4:</u> **The effects of site preparation on the height's current annual increment (CAI) of *E.camaldulensis* and *E.grandis* over four years after planting.**

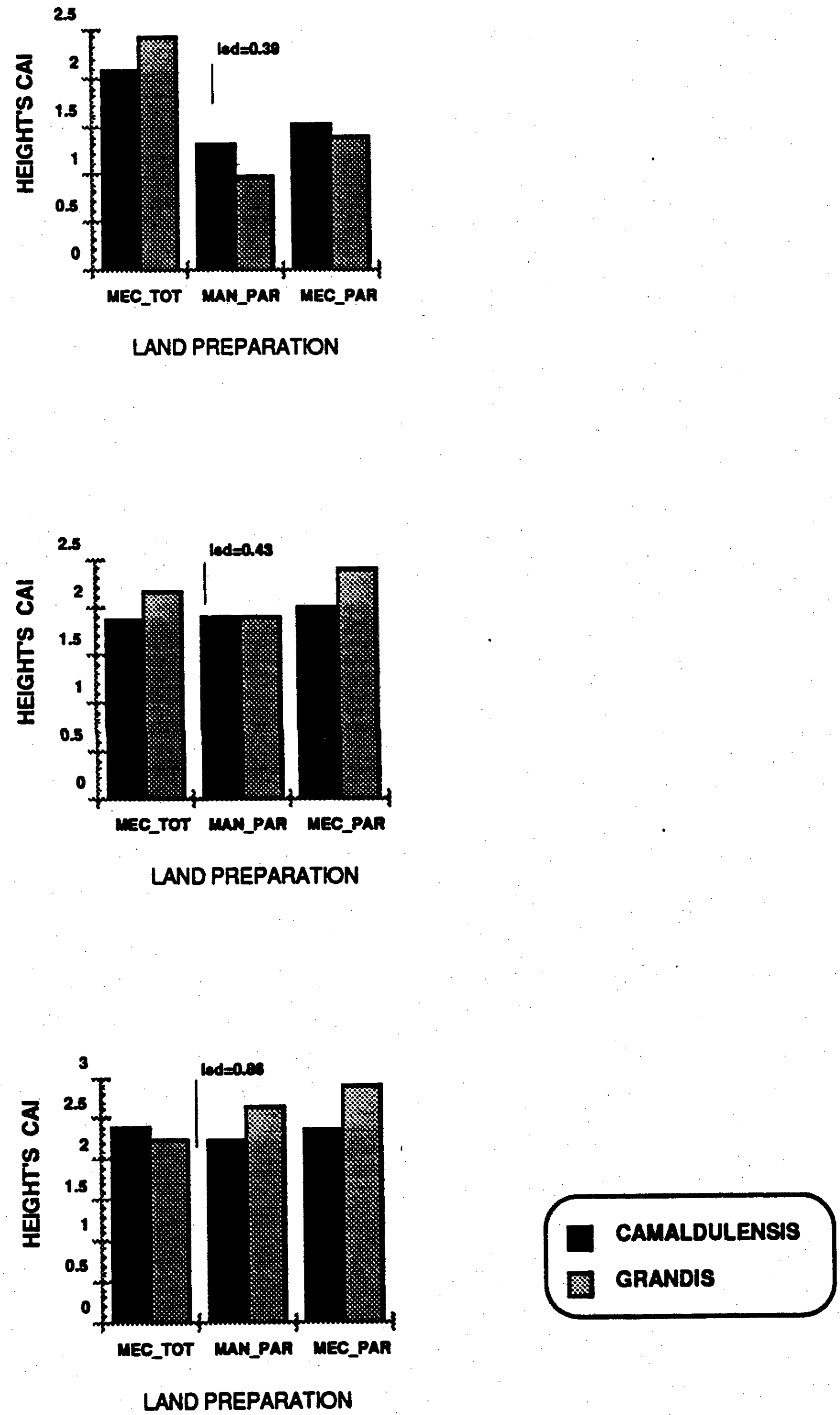
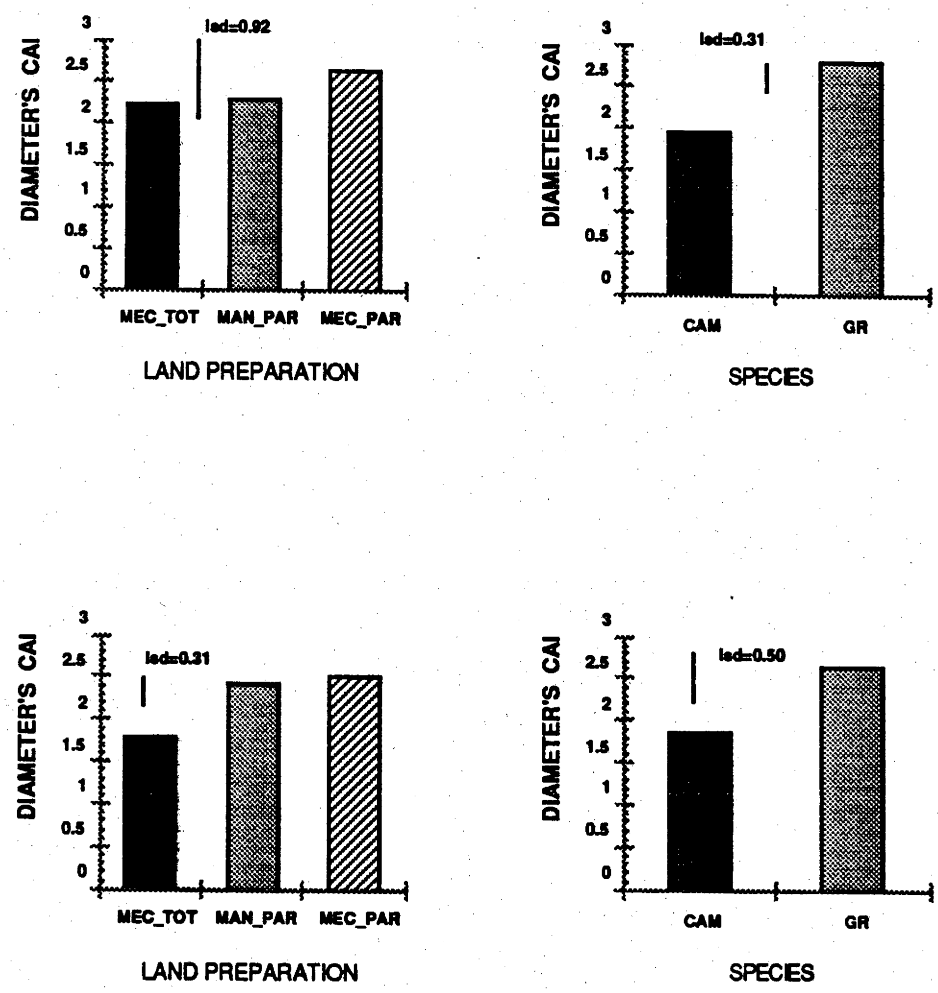


FIGURE 2.5: The land preparation and the species main effects on the diameter's current annual increment (CAI) of trees at three and four years after planting.



2.3.3. The health condition of the trees

Analysis of the data:

A logistic regression analysis for the binomial response variable of the probability of trees being healthy was effected. The accumulated analysis of deviance as shown on Table 2.7 for age three years showed a nearly significant interaction of fertilizer x species on the response variable which was maintained at four years of age. In addition, at four years old, there was a significant effect of land preparation as well as the main effects of fertilizer and species.

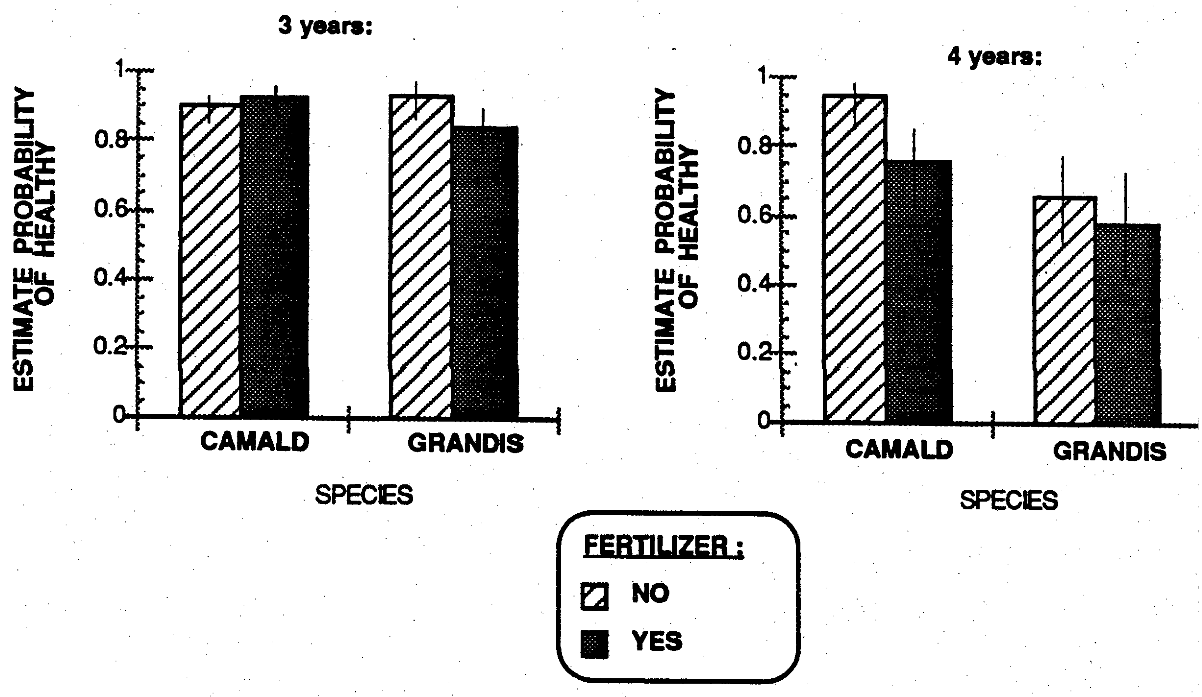
TABLE 2.7: **The accumulated analyses of deviance for the probability of *eucalyptus* trees being healthy at three and four years of age. The table shows the significant effects at P< 0.01.**

Age	Change	d.f.	Deviance	Mean deviance	Deviance ratio
3 years	Fertilizer. Species	1	4.843	4.843	1.70
	Residual	21	59.708	2.843	
	Total	34	84.077	2.473	
4 years	Land preparation	2	11.375	5.687	5.66
	Fertilizer	1	5.366	5.366	5.34
	Species	1	17.209	17.209	17.11
	Fertilizer. Species	1	4.508	4.508	4.48
	Residual	21	21.116	1.006	
	Total	34	73.024	2.148	

Results:

Fertilizer reduced the health of both species. This was evident at age three years in *E.grandis* but not until age four years in *E.camaldulensis* (Figure 2.6). The latter was healthier than *E.grandis.*

<u>FIGURE 2.6:</u> The effect of fertilizer on the probability of trees of *E.camaldulensis* and *E.grandis* being healthy at three and four years old.



† **the bars represent the limits of 95% Confidence Interval for the predicted values.**

Even though health of trees decreased from age three to age four, the mechanical site preparation produced a noticeably larger number of healthy trees compared to the manual site preparation (Table 2.8).

TABLE 2.8: **The number of healthy trees in each of the three land preparation procedures at three and four years of age.**

LAND PREPARATION	3 YEARS	4 YEARS
MECHANICAL - TOTAL WEEDING	213	110
MECHANICAL - PARTIAL WEEDING	191	94
MANUAL - PARTIAL WEEDING	118	64

2.3.4. Stem form quality of trees

Analysis of the data:

The multinomial response variable for four classes of stem form (A, B, C, D) was analysed by a log-linear analysis of a multiway-contigency table. The accumulated analysis of deviance is shown in Table 2.9 for three and four years of age.

Highly significantly differences in stem of form were shown by the species in both years. A significant land preparation effect was observed in the third year but not in the fourth. (n.b. The statistics are based on the assumption of independence between trees. The analysis showed some evidence that this may not be the case. Hence, caution is necessary in the inference of statistical significance for the land preparation effect).

TABLE 2.9: **The accumulated analysis of deviance for the significant effects ($P < 0.01$) of species and land preparation on the stem form quality of eucalypts trees at three and four years old.**

AGE	CHANGE	d.f.	Deviance	Mean Deviance	Deviance ratio
3 years	Plot				
	Stem form	38	219.930	5.788	2.42
	Stem form. Land preparation	6	25.985	4.331	1.81
	Stem form. Species	3	70.805	23.618	9.89
	Residual	96	229.330	2.389	
	Total	143	546.098	3.819	
4 years	Plot				
	Stem form	38	138.609	3.648	2.94
	Stem form. Species	3	56.356	18.785	15.16
	Residual	102	126.433	1.240	
	Total	143	321.399	2.248	

Results:

The patterns of the distribution of the trees per classes of stem form (from **A** - the best form, to **B**, **C** and **D** - the worst form) varied with species (Table 2.10). *E.grandis* had better stem form than *E.camaldulensis*. At 3 years old, *E.grandis* had 44% of the trees with stem form **A** compared to the 16% on *E.camaldulensis*.

By age four years, the species differences were still evident but there had been an overall deterioration on the stem form of the trees. The percentage of trees in classes **A+B** had decreased to 64% and 37% (*E.grandis* and *E.camaldulensis*, respectively) while the percentage of trees on the classes **C+D** increased.

<u>TABLE 2.10:</u> The percentage (%) number of trees per each stem form per species, at three and four years after planting.

AGE	SPECIES	STEM FORM A	B	C	D
3 years	CAMALDULENSIS	16	45	29	11
	GRANDIS	44	32	11	13
4 years	CAMALDULENSIS	2	35	48	16
	GRANDIS	26	38	21	16

The site preparation and weeding treatments affected stem form. The trees were of much poorer form on plots with manual preparation and partial weeding (Table 2.11). Both mechanical site preparation procedures produced over 70% of trees with form A and B compared to 51% produced on the manual site preparation.

TABLE 2.11: **The effect of land preparation on the percentage (%) of trees per class of stem form at three years old.**

LAND PREPARATION	STEM FORM			
	A	B	C	D
MECHANICAL-TOTAL WEEDING	26	45	15	14
MECHANICAL-PARTIAL WEEDING	33	39	19	9
MANUAL-PARTIAL WEEDING	17	34	38	11

2.3.5. Maturity stage of the trees

Analysis of data:

A logistic regression analysis was used where the binomial response variable was "the probability of the trees being immature". The summarized accumulated analysis of deviance is shown in Table 2.12 for the significant effects at age three and four years. The highly significant difference of the species on the immaturity of the trees observed at three years old was maintained by four years old. Similarly, the significant effect of land preparation on the probability of trees being immature was also maintained at four years of age.

TABLE 2.12: The accumulated analysis of deviance for the significant main effects (P< 0.01) on the probability of eucalypts trees being immature at three and four years after planting.

AGE	CHANGE	d.f.	deviance	mean deviance	deviance ratio
3 years	Land preparation	2	30.973	15.486	7.67
	Species	1	111.963	111.963	55.42
	Residual	21	42.427	2.020	
	Total	34	226.151	6.651	
4 years	Land preparation	2	7.832	3.916	1.30
	Species	1	38.084	38.084	12.67
	Residual	21	63.133	3.006	
	Total	34	134.647	3.960	

Results:

The *E.grandis* trees were more immature than *E.camaldulensis* trees of the same age (Table 2.13). So too were the trees grown on plots with manual site preparation (Table 2.14).

TABLE 2.13: The predicted probability of trees of *E.camaldulensis* and *E.grandis* being immature at three and four years old.

AGE	SPECIES	PREDICTED	STANDARD ERRORS
3 years	CAMALDULENSIS	0.47	0.04
	GRANDIS	0.93	0.02
4 years	CAMALDULENSIS	0.21	0.04
	GRANDIS	0.52	0.05

TABLE 2.14: The predicted probability of Eucalypts trees being immature by the effect of land preparation, at three and four years after planting.

AGE	LAND PREPARATION	PREDICTED	STANDARD ERRORS
3 years	MECHANIC-TOTAL WEEDING	0.47	0.04
	MECHANIC-PARTIAL WEEDING	0.63	0.04
	MANUAL-PARTIAL WEEDING	0.87	0.03
4 years	MECHANIC-TOTAL WEEDING	0.21	0.04
	MECHANIC-PARTIAL WEEDING	0.24	0.04
	MANUAL-PARTIAL WEEDING	0.40	0.06

2.4. DISCUSSION

Site preparation:

Survival and growth of the trees was affected by the land preparation techniques with mechanical site preparation proving far superior to manual clearing. The purpose of site preparation is to secure high survival and rapid early growth. Cultivation of the soil can achieve this in two ways: (i) It may affect the structure and texture of the soil and produce a more rapid mineralisation of organic matter, better soil drainage, aeration and water percolation, and (ii) it may destroy weeds, so reducing competition from non-crop vegetation for limited soil moisture and nutrients (Cleary, 1983; Cromer, 1984a; Donald, 1984; Schönau, 1985; Newton *et al.*, 1986; Evans, 1992).

Soil structure and texture influence tree growth and anchorage by affecting the way the root system spreads through the soil. Cultivation can improve the growth of the main roots of a tree (Newton *et al.*,1986; Coutts, 1989; Colin-Belgrand *et al.*, 1989) and exerts great control over root system form (Sutton, 1969). For example Boden (1984, 1991), working with *E.grandis* in Natal - South Africa, demonstrated that ploughing improved the tilth, removed the grass in the upper profile and resulted in rapid root system development (by 30 months of age) with large and strong lateral roots and a dense mat of finer roots. The tap root was overshadowed by the lateral components. In contrast, when the only cultivation was a planting pit, the roots faced considerable barriers in penetrating the surrounding mass of grass roots and the firm soil. The result was a root system with a few, small lateral roots and bad tap root development.

The sandy soils on which the Mozambique trial was established have little structure and possess good drainage. When dried, a thin crust is formed on the soil surface. Cultivation improves conservation of soil moisture and also breaks the crust thus improving soil aeration and water percolation. In addition, it loosens the soil, decreasing mechanical impedance to root extension. Porous, coarse-texture sands and fine gravels constitute a very rigid soil system and can create as much mechanical impedance to a root as a compacted or cemented soil horizon such as a fragipan (Armson, 1977).

Weed control:

Weed control may be as equally important as soil condition for plantation establishment, as an undesirable vegetative cover can seriously impair the survival and growth of the plantation (Chapman and Allan, 1978). It affects the time required for a stand to reach a given stage of development and maturity (Snowdon and Khanna, 1989). Rapid establishment of a tree crop is important. Reducing the time taken to reach canopy closure and avoid shading from non-crop plants, increases the amount of solar radiation intercepted by the crop and thus allows the trees to produce more carbohydrates and allocate proportionally more assimilates to stemwood (Cromer, 1984a). The rapid domination of the site increases crop uniformity (Chapman and Allan, 1978). In a plantation, once the canopy is closed many of the hazards to which it is prone greatly diminish (Evans, 1992). Boden (1984) recommended that prepared areas for *E.grandis* should be kept clear of weeds until canopy closure is effected - i.e., till approximately 2.5 years of age.

The linkage of cultivation and weed control agrees with the results of Cromer (1984a) working with sub-tropical pines and Donald (1984) working with both pines and eucalypts, in South Africa. These authors found that complete cultivation was highly effective and seldom required additional weed control whereas pitting required maximum weed control.

In the Mozambique trial the effectiveness of weed control through site cultivation varied with the intensity of cultivation. Both mechanical site preparation procedures gave superior results to manual site preparation (Figure 2.3). However, after three years, with the mechanical site preparation, there was no difference observed between total weeding and partial weeding. This indicates that mechanical cultivation prior to planting is effective but partial weeding may be adequate once the trees are established.

Most deaths occurred during the first year after planting (Figure 2.2) but some mortality was still observed up to four years after planting. However, *E.camaldulensis* exhibited markedly lower mortality than *E.grandis* in all treatments (Figure 2.2). Six months after planting, the overall percentage mortality was 15% in *E.camaldulensis* but 58% in *E.grandis*.

Weed growth during the first and second month is the most detrimental factor acting on young eucalypts seedlings - due to shading, allelopathy, competition for nutrients and/or soil moisture stress (Schumann, 1992). Later, the suppressive influence of weeds is mainly through underground competition. The strong competition offered by weeds to the growth of many tree species derives from their ability to extend roots into soil whose moisture content is well below permanent wilting point. The density of absorbing roots strongly affects initial rates of water and nutrient uptake and so too does competition among plants with roots in the same soil volume (Stone and Kalisz, 1991). Thus, the ability of a plant to compete for moisture depends largely on the number and position of its roots in relation both to other roots and to soil moisture (Sutton, 1969).

In the study the two species exhibited a species x weed interaction. When the area had been totally cleared the absolute height growth of *E.grandis* was greater than *E.camaldulensis* (Figure 2.3) but, on partially cleared areas, *E.camaldulensis* was greater. However this difference only lasted up to two years. Similarly, the absolute diameter growth of *E.grandis* was greater than *E.camaldulensis* and more noticeable on the total cleared areas. This difference was most evident after the second year of planting (Figure 2.3).

Therefore the data indicate that, in the initial stage of development, *E.grandis* cannot compete with weeds as successfully as *E.camaldulensis*. However, once the surviving trees are established - which happens the second year after planting - the species' growth rates increase. *E.grandis* then tends to perform better than *E.camaldulensis*. Figure 2.4 shows that the growth of both species increased steadily on the partial cleared areas, indicating the overcoming of weed competition.

Diameter increment was greater, overall, in *E.grandis* than *E.camaldulensis*. Here too the Current Annual Increment was greater on the partial weeded areas (Figure 2.5) on both mechanical site preparation. Presumably as the trees overcame competition they increase increment. This indicates that weeds are the most detrimental factor to early plant growth.

Bila (1988) reported similar results where *E.camaldulensis* outperformed *E.grandis* in height on three different levels of site preparation at seven months of age. After the first year, the reverse occurred with his mechanical site preparation but *E.camaldulensis* retained superiority on the manual site preparation.

Species and site interaction:

These results reinforce the great importance of relating species to silviculture and emphasise that the process of matching seedlings to the planting environment does not end once the choice of species has been made (Hobbs, 1983). Many species and provenances have shown interactions with environmental conditions (Donald, 1984; Kageyama *et al.*, 1988) elsewhere.

For instance, Darrow (1983) found that *E.camaldulensis* showed higher survival rates than *E.tereticornis* when grown in both humid and dry areas of South Africa. However, in the more humid areas, *E.tereticornis* outperformed *E.camaldulensis* in height and basal area growth and stem quality. In the dry areas, with heavy frosts, *E.camaldulensis* was superior unless the water table was high.

Similarly, Kageyama *et al.* (1988) reported that 12 different Eucalypts species at seven years of age ranked differently when planted in two different sites in Minas Gerais (Brazil). *E.camaldulensis* ranked first on what the author termed as the less favourable sites of Paraobeba but last on the more favourable sites of Viçosa whereas *E.grandis* maintained the second position in both sites. Moreover, in Alagoinhas (Brazil), in a soil with low levels of fertilizer, *E.citriodora* and *E.paniculata* were superior in growth to *E.grandis* and *E.urophylla* at two years of age. With high levels of fertilizer, the reverse occurred.

In the species/provenance trial established in Michafutene - Mozambique, Cezerilo (1990) reported that at two years of age the height of *E.tereticornis* was superior to *E.camaldulensis* and *E.brassiana* when planted on white soils. But, on red soils, *E.brassiana* was superior to both the others. However, there was a change with age: by four years of age *E.camaldulensis* was superior to the other species on both sites. This indicates great care is needed when interpreting the data and early conclusions could be in error.

Fertilizer:

Fertilization has normally been used to promote survival and/or growth where specific nutrient deficiencies are the primary limiting factors (Newton *et al.*, 1986). Applications before planting may improve survival and growth over the entire rotation being essential to successful stand establishment (Fisher and Mexal, 1984).

However, it may increase competition for limited moisture reserves. Fertilization stimulates weed growth which, if not controlled, detrimentally affects early performance (Barker, 1978; Schumann, 1992).

A rapid response of weeds to fertilizer may reduce the availability of the nutrients to the tree and increase competition for light and soil water (Donald, 1984; Fisher and Mexal, 1984). This is especially so if adequate rainfall and generally moist conditions do not prevail (Chapman and Allan, 1978; Fisher and Mexal, 1984; Donald, 1984). In dry zones, the increased mortality of newly-planted areas can be caused by high concentrations of the fertilizer salts in the soil solution (mainly due to nitrogen in the fertilizer) if adequate rainfall does not follow (Fisher and Mexal, 1984; Schönau, 1984). Ballard (1978) suggested that mortality can be caused by the placement of the fertilizer too close to seedlings' root systems.

Nutrient content and distribution in the soil profile exert an influence on the development of roots (Baule and Fricker, 1970). Surface roots which originate from the upper part of the tap root have their orientation modified by the environment (Coutts, 1989). The spatial distribution of a root mass can be altered by the local proliferation of roots into zones of high nutrient supply (Boot, 1989). It has been suggested that the shape and the spatial extension of root systems is markedly influenced by the rate and patterns of nutrient uptake from the soil (Colin-Belgrand *et al.*, 1989). Cromer (1984b) observed that partitioning of dry matter to the roots of *E.delegatensis* decreased from 0.4 in nutrient deficient plants to 0.1 in those supplied with adequate nutrients. Boden (1984) found in *E.grandis* that strong lateral roots with a mass of finer roots had developed and radiated outwards at the point of fertilizer placement.

Fertilizer increased mortality in the *E.camaldulensis* but decreased it in *E.grandis* (Figure 2.2). This may be explained by the effect of fertilizer on their respective root systems. In *E.camaldulensis*, normally with an inherent deep root system, the fertilizer may have caused development of the surface roots to the detriment of deep roots thus making the trees more susceptible to drought in the upper layers of the soil. Whereas, in *E.grandis*, with a superficial rooting system, the fertilizer may have increased proliferation of these thus increasing soil exploration and the effective area for the absorption of water and nutrients, and so increasing the plant's susceptibility to drought.

Fertilizer did not affect growth. Bila (1988) found similar results in São Paulo (Brazil), on sandy soils with low content of organic matter (93% sand; 2.3% M.O.). At seven months of age, trees of *E.camaldulensis*, *E.grandis* and *E.citriodora* with mechanical site preparation outperformed trees with manual site preparation regardless of fertilization. This reinforces the finding of the Mozambique study that slow initial growth of eucalypts is associated with the development of root system and presence of weeds and is related to the water status of both soil and plants.

However, it should be noted that greater survival, height, diameter and volume of *E.grandis* to fertilizer applications were maintained till clearfelling have been reported elsewhere (Herbert, 1983; Cromer, 1984b; Donald, 1984; Cromer and Jarvis, 1989; Schönau and Herbert, 1989; Barros *et al.*, 1992). This is especially effective when combined with site preparation treatments, such as ploughing followed by disc harrowing and complete weeding (Boden, 1984; Schumann, 1992). For example, Boden (1984) found an increase in 124% on the height of *E.grandis* when a combination of fertilizer and one or more methods of site preparation was applied compared to the fertilized plots with no site preparation which was amongst the poorest treatments.

Death of older trees:

That established trees continue to die after four years or more is a cause for concern. It is possible the nutrition x species effects are long term.

Die-back in eucalypt plantations in Maputo (Mozambique) is common and worse when dry conditions prevail (Pessoa, 1984). The symptoms first appear as a twisted distortion of young leaves and the browning of the upper foliage which progresses down the tree. Later, death of apical growing tips, defoliation and progressive dieback of shoots occur.

These are symptoms of a trace element deficiency. It has been suggested that, in many savanna areas, the dieback which develops during the dry season and causes frequent death of eucalypts is due to boron deficiency (Savory, 1962; Cooling and Jones, 1970; Chapman and Allan, 1978; Pessoa, 1984; Herbert and Schönau, 1989; Barros *et al.*, 1992). The deficiency becomes critical in dry soil (Savory, 1962). The Mozambique experiment was carried out during the recent severe drought period in Southern Africa. During this period, the mean annual rainfall at the site of the experiment dropped by 20 % (627,9 mm) in 1989 (rainfall data of Ricatla station).

There have been many reports of decreased resistance to disease and to frost by eucalypts due to boron deficiency (Shorrocks, n.d.; Cooling and Jones, 1970). Boron deficient eucalypts exhibit cracks and splits on the petioles and on the stem, where the bark becomes dark brown and necrotic. Pessoa (1984) reported the occurrence of other diseases on eucalypt plantations caused by *Diaporthe spp.* and *Phoracantha spp.*. The splits and cracks on the shoots and stems facilitate attack by these species.

Pessoa (1984) observed that *E.camaldulensis* and *E.tereticornis* in Mozambique, are less susceptible to dieback and other diseases than are *E.grandis* and *E.saligna*. In the reported study the health of *E.grandis* was poorer than that of *E.camaldulensis* and worsened with the years (Figure 2.6).

The greater decrease (to 60%) in the probability of *E.grandis* trees being healthy may indicate this species has been under more stress than *E.camaldulensis*. According to Evans (1992), trees under stress are more susceptible to insect pests, fungal diseases and other adverse agents.

The application of fertilizer did not improve this situation as it reduced health of both species. This detrimental effect of fertilizer was observed earlier on *E.grandis* (Figure 2.6). Very often, attacks of diseases and of pests are the consequence of a bad state of nutrition of the trees (Baule and Fricker, 1970). According to Finck (1982) the natural resistance of plants to diseases can be reduced by excessive as well as insufficient supplies of one or more nutrients. Since the protective mechanisms and defences of trees have been weakened, additional disturbance of the metabolism promotes attack.

However, mechanical land preparation had a positive effect on the health of trees (Table 2.8). This suggests that trees may be less stressed on these two land preparations which might have improved the water status of trees.

Form quality

Stem form development is inherited. However, it may be modified by many environmental factors and by silvicultural practices (Larson, 1963).

In the field trial *E.grandis* had better stem form than *E.camaldulensis* overall (Table 2.10). The stem form quality decreased with time by producing more trees with class "C".

Stem form was also affected by the site preparation but not by fertilization. The mechanical site preparation produced trees with better form(Table 2.11) even though this effect had disappeared at four years of age. The results also suggest an initial effect of the weeds as more trees with stem form "A" were produced on the partially weeded plots.

Maturity:

All trees undergo a period of juvenility before they will flower and fruit. The length of the juvenile period shows great variability among species and is under genetic control (Sedgley and Griffin, 1989).

In the field study, trees of *E.camaldulensis* matured earlier than *E.grandis*. Table 2.13 shows that, at four years of age, only 21% of the former were immature compared to 52% for the latter. Mechanical site preparation promoted number of mature trees in both species (Table 2.14) but fertilization had no effect.

According to Kozlowski (1971) and Sedgley and Griffin (1989) the initiation of flower primordia can be modified by those environmental factors which influence growth rate and tree vigour. Shortening of the juvenile phase can be achieved by growing seedlings under conditions which stimulate continuous or vigorous growth (Hackett, 1985 cited by Sedgley and Griffin, 1989). As the initiation of flower primordia may require the trees to reach a minimum size (Kozlowski, 1971) the beneficial effects of soil cultivation may promote and improve flower production (Zobel and Talbert, 1984).

Sedgley and Griffin (1989) identified some trends relating environment to flower induction in tree crops: (i) the nutritional status of the tree where nitrogen improves flowering in most tree crops by affecting tree growth rate or size; (ii) shoot length, by which longer shoots produce more flowers than shorter shoots; (iii) water stress may promote floral initiation but may have a negative effect on flowering if stress levels inhibit vegetative growth at other stages of development and, (iv) temperature. Other cultural treatments which influence flowering include (i) gravity and girdling and (ii) growth-regulating chemicals.

It appears that both stem form and maturity of trees are closely related with growth and size of trees. Results of the field study show that growth was affected by land preparation (better performance on mechanical site preparation) but not by fertilizer. The absence of a growth response to fertilizer may explain the lack of a response in both form and maturity.

2.5. CONCLUSIONS

Summarized conclusions are presented in the next Chapter as part of the discussion establishing the rationale for the latter experiments.

CHAPTER 3

Justifying the study

3.1. THE FINDINGS OF THE FIELD STUDY

The field study described in Chapter Two compared the performance of two eucalypt species, *E.camaldulensis* and *E.grandis*, over four years in Maputo province (Mozambique) under different conditions of site preparation and weeding. This study showed:

(i) The mortality of trees was important. Although most mortality occurred during the first year of planting it continued for at least four years. The two species differed considerable in mortality being significantly greater in *E.grandis*.

The absence of weeds allied with intensive land preparation resulted in decreased mortality in both species. (The application of fertilizer decreased mortality in *E.grandis* but increased it in *E.camaldulensis*).

(ii) The growth of the *Eucalyptus* trees was affected by land preparation but not by fertilizer. Mechanical site preparation produced bigger seedlings than manual site preparation.

Although total, as opposed to partial, weeding improved performance of the trees, the increase was not significant when mechanical site preparation was done. This indicates that mechanical cultivation prior to planting is effective and partial weeding may be adequate once the trees are established.

In the initial stage of development, *E.grandis* could not compete with weeds as well as *E.camaldulensis*. Later, *E.grandis* exhibited increased growth on the partially weeded areas. This suggests it was overcoming weed competition. In contrast, no difference was observed in the performance of *E.camaldulensis* on the three types of land preparation.

It is well known that weeds are an important factor in eucalypt establishment and growth (Chapman and Allan, 1978; Boden, 1984; Newton *et al.*, 1986; Schumann, 1992). The results of the experiment support this but indicate the effect of weeds may vary with different species. A lack of response to fertilizer suggested the effect of the weeds on the initial growth of eucalypts was associated with the availability of water to both species rather than of nutrients.

3.2. THE RATIONALE FOR FURTHER STUDY

The identification of the environmental factors most likely to exert the strongest influence on seedling performance (survival and growth) is an important prerequisite to successful plantation establishment (Hobbs, 1983). Climate, soil and silvicultural practices influence the operational environment where seedlings grow (Hobbs, 1983; Gjerstad *et al.*, 1984; Schönau and Herbert, 1989).

Silvicultural factors affect yield of fast growing plantations (Boden, 1984; Donald, 1984; Cromer, 1984a; Schönau, 1985; Kageyama *et al.*, 1988) and different species, provenances and even progenies have different requirements and different tolerances to deficiencies. Therefore, the use of optimum silvicultural techniques allied with the correct site and species selection may enable sites with below optimum climatic conditions to be used for production with *Eucalyptus* species (Hobbs, 1983; Schönau, 1985).

Site amelioration through cultivation and weeding can improve tree survival and growth (Cromer, 1984a). The beneficial effect of cultivation is often equated with weed control even though more rapid mineralization of organic matter, better soil drainage and water percolation and greater rooting depth are also contributing factors (Francis, 1984; Schönau, 1985). A weed is a plant out of place, an undesirable and unwanted plant (Crafts and Robbins, 1962; Muzik, 1970). They are often prolific and persistent and compete with newly-planted trees for soil moisture and nutrients reducing survival and yields. From seedling establishment to canopy closure, tress are making increasing demands on soil moisture and nutrients. Competition with weeds becomes vital when the available supply of moisture and nutrients are well below the demands of both trees and weeds and insufficient to guarantee each individual optimal survival and growth (Gjerstad *et al.*, 1984; Rice, 1985). Thus the importance of weeding is especially important in dry climatic zones.

The size of root systems is often reduced when trees are grown in competition for limited water and nutrients (Chaney, 1981). The final dimensions of their roots are dependent on their initial competitive ability, access to water and to the nutrient contents of the soil where they grow (Riedacker and Belgrand, 1983; Gjerstad *et al.*, 1984).

Root systems can also be modified by genetic factors as they are dependent on the morphological and physiological characteristics of the trees (Sutton, 1969). In addition, they can be modified by environmental and edaphic factors (Baule and Fricker, 1970; Armson, 1977; Chaney, 1981; Burdett *et al.*, 1983; Nambiar, 1983).

The different performance of the species under conditions of weed competition in the field indicate the importance to examine the effects of weeds in the more controlled conditions of a glasshouse trial. A glasshouse trial could examine in detail the comparative performances of trees, weed growth and competition with respect to the species, and to provenance variation within the species, on different soil types and with different water regimes. If successful, similar trials might be used to predict performance of untried species and provenances in field conditions.

CHAPTER 4

The glasshouse studies on the species/provenances differences in response to different soil, weeds and water treatments.

4.1. THE PROPOSED STUDY

Chapter Three noted that weeds limit the ability of trees to respond to favourable conditions and the effects of weeds on the growth of trees were explained in relation to competition for water though competition for nutrients may also be important. Characteristics such as the rapid development of foliage and the rapid growth and size of root systems may enable a species to compete successfully with weeds during its initial stage of establishment. The field study has shown differences in survival, growth rate and quality between *E.camaldulensis* and *E.grandis* when in competition with weeds.

To help in the selection of species and provenances most suited to the conditions of the Maputo region, two glasshouse experiments were conducted to complement the field experiment. Provenances of both *E.grandis* and *E.camaldulensis* from different habitats were used in the experiments. In the first experiment, the effect of weeds on the development of the two species when grown in two types of soil (sandy and clay) was assessed. In the second experiment, seedlings of *E.camaldulensis* were raised in competition with weeds in different water regime treatments (high and low levels).

The studies were designed to:

(i) compare the effects of weeds on the growth of *E.grandis* and *E.camaldulensis* in two different soils.

(ii) determine if the presence of weeds could contribute to the observed field mortality of eucalypts seedlings by inhibiting growth and root development.

(iii) compare the performances of different provenances of *E.camaldulensis* (from different habitats) under grass competition and water deficiency, specifically to determine:

- whether there exists a significant interaction between provenances, grass and water;
- if differences do exist, which provenance will be best to use in such harsh conditions of sandy soil with grass competition and water deficiency.

4.2. MATERIAL AND METHODS

4.2.1 The first glasshouse experiment

The experiment was conducted in the Glasshouse (Forestry/Botany) at ANU, from 3 rd of July till 11 th of December 1990.

Species and seed origin:

Two provenances (one from the North and one from the South of Australia) each of *E.grandis* and *E.camaldulensis* were selected. Seeds with the details of the collection shown on Table 4.1. were supplied by CSIRO. The weed seed used in the experiment was "Victorian Rye Grass" (*Lolium spp.*).

TABLE 4.1: **The seed sources of the *Eucalyptus* species used in the first glasshouse experiment.**

SPECIES AND SEEDLOT NO.	NO. OF PARENT TREES	LOCALITY	ORIGIN			VIABLE SEEDS/ 10 g	QUANT g
			LAT. deg	LONG. deg	ALTIT m		
E.camaldulensis: 14338	129	Region E. of Petford (QLD)	17º 17' S	145º 3' E	500	9800	10
E.camaldulensis: 15027	12	Lake Albacutya (VIC)	35º 48' S	141º 58' E	70	4133	10
E.grandis: 16447	4	Near Coffs Harbour (NSW)	30º 13' S	152º 56' E	630	6600	10
E.grandis: 14709	10	W. of Wandecla (QLD)	17º 23' S	145º 27' E	980	5870	10

* no pre-treatments required prior to sowing.

Phases of seedling growth:

Seedlings were raised and grown through three phases: Germination stage, transition stage and final stage.

(i) The germination phase

To obtain 72 seedlings of each species for the experiment, approximately 0.2 g of seeds for each species were used (Table 4.2).

TABLE 4.2: **The amount of *Eucalyptus* seeds per species and provenances used in the experiment.**

SPECIES/PROVENANCES	VIABLE SEEDS / 10 g	NUMBER SEEDLINGS NEEEDED	TOTAL gr SOWN
1.- ***E. camaldulensis*** - E. of Petford (QLD)	9800	72	0.10
2.- ***E. camaldulensis*** - Lake Albacutya (VIC.)	4133	72	0.22
3.- ***E. grandis*** - Near Coffs Harbour (NSW)	6600	72	0.14
4.- ***E. grandis*** - W. of Wandecla (QLD)	5870	72	0.16

Seeds were sown on small germination trays containing a 1:2 mixture of vermiculite and perlite . The same mixture was used to cover the seeds after sowing. The trays were watered before and after sowing.

During the germination phase, from 3 rd July 1990 (sowing) till 20 th July (pricking-out), the trays were maintained under an automatic watering system for the first 10 days and after that received manual watering twice per day. The glasshouse conditions recorded during this phase are shown on Table 4.3.

TABLE 4.3: The glasshouses mean temperatures during all the phases of seedling growth.

MONTH	MAXIMUM TEMPERATURE	MINIMUM TEMPERATURE
JULY	19.2	13.2
AUGUST	21.3	14.8
SEPTEMBER	21.2	14.5
OCTOBER	25.0	15.7
NOVEMBER	28.1	18.2

A soluble fertilizer "Hortic Aquasol"[1] was applied once per week after germination of seeds during this phase.

The seeds started to germinate on the 10 th of July (*Eucalyptus camaldulensis* - Lake Albacutya) and they were pricked-out on the 20 th of July (Table 4.4) .

1 Hortic Aquasol consists of NPK (23:4:18) and was applied at a concentration of 1 g/litre of water.

TABLE 4.4: **The dates and total number of seedlings germinated and produced.**

SPECIES	INITIAL DATE OF GERMINATION	NUMBER SEEDLINGS EXPECTED	NUMBER SEEDLINGS PRICKED-OUT	NUMBER SEEDLINGS PRODUCED
1. *E. camaldulensis* Petford	11/07/90	98	86	78
2. *E. camaldulensis* L. Albacutya	10/07/90	91	102	88
3. *E. grandis* N.C.Harbour	12/07/90	92	88	83
4. *E. grandis* W.Wandecla	12/07/90	94	120	116

(ii) Transition stage

Seedlings were pricked-out to small pots (5 cm diameter x 6.5 cm height) containing the following mixture at pH 5.8:

> 1 Perlite : 1 Peat moss : 1.5 rotted bark : 2 sand : sterilized black soil : Osmocot[2] (3kg/1m^3 of all media) : Microplus[2] (270-300 grams/1m^3 of all media) : Garden lime (7kg/1m^3).

The pots were maintained in glasshouses till 6 th August when the experiment was finally established. See Table 4.3 for the glasshouse temperatures during this stage.

Watering was carried out twice daily.

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2 Both are registered names.

(iii) Final stage

To establish the experiment, black polethylene pots, 55 cm deep and 20 cm in diameter, were filled with two different types of soil mixed manually: clay soil containing 1 part of clay and 1 part of sand and sandy soil containing 3 parts of sand and 1 part of clay. The clay soil was turned over and passed through a 5 mm^2 sieve.

The whole process of soil preparation and mixing, filling pots and arranging them in the glasshouse took place from 7 th Sept till 24 th Sept 1990. All the pots were watered to field capacity before transplanting the seedlings.

The seedlings were classified according to height, so that seedlings of similar size could be transplanted to the same block. They were transplanted from 25 th Sept to 27 th Sept.

Pots with "weed" treatment had the seeds of "Victorian rye grass" sown on 28 th Sept at a rate of 1.3 gr per pot.

Watering was carried out twice a day during the two weeks after 28 th September to allow the establishment of the *Eucalyptus* seedlings and the germination of the weeds. Weed germination was better in clay soil and, in order to get approximately the same amount of weed in all the pots, an extra sowing was made in those with sandy soil. Consequently, over two weeks, the latter received more water. For the sandy pots watering was carried out once every day and for the clay pots once every two days.

One and a half months after transplanting the seedlings started to show stress i.e. the leaves started to wilt. So, watering was reduced to once every four days.

The design and layout of the experiment:

The pots were arranged using a split split plot design with 4x2x2, three replicates and a total of 288 pots. Thus, there were 16 treatment combinations allocated in three Blocks:

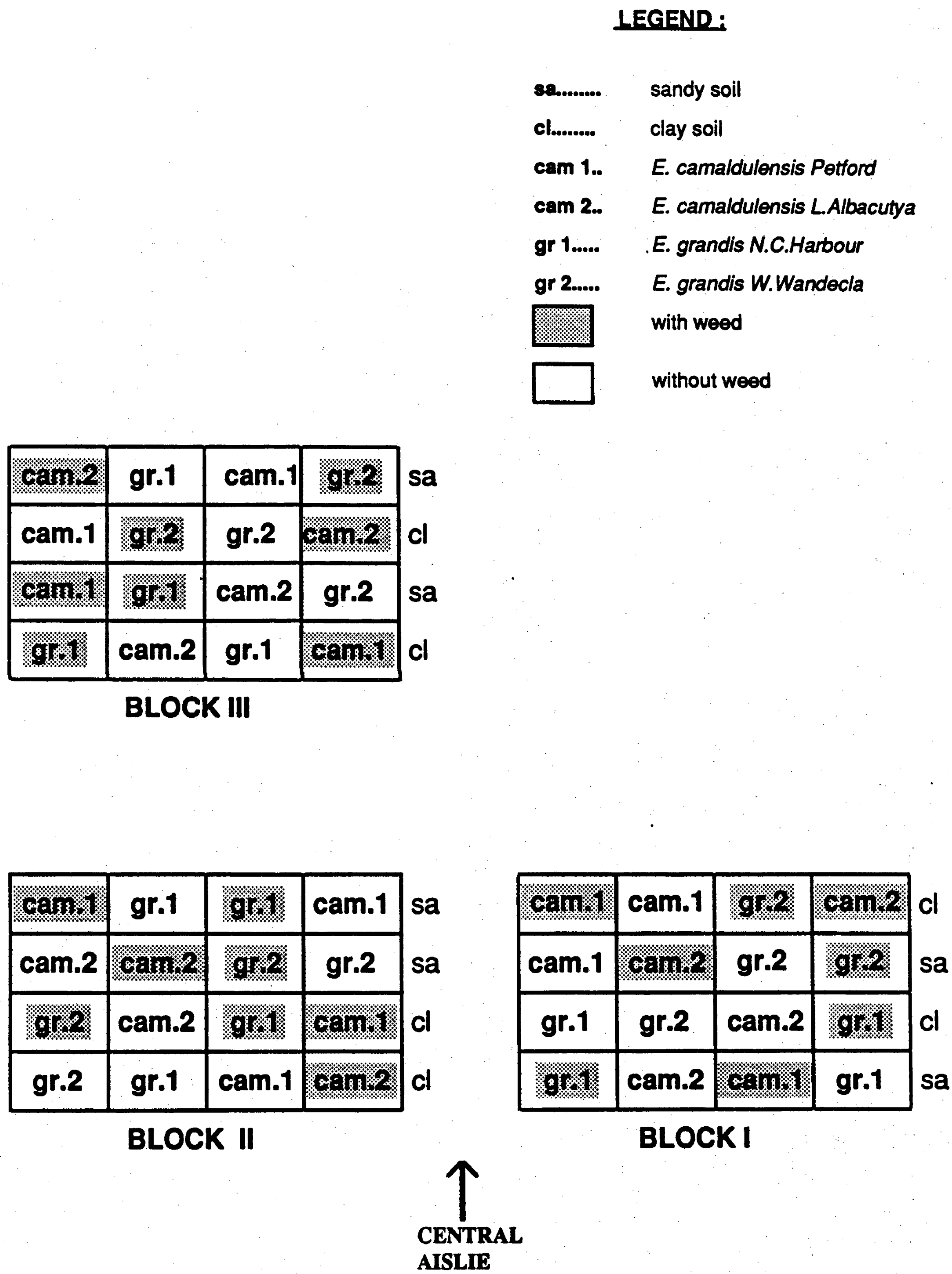
(i) Two species of *Eucalyptus*: *grandis* and *camaldulensis* and two provenances of each species: one from North and one from South (see Table 4.1 for details);

(ii) Two soil types: sandy and clay;

(iii) Two levels of weed: with and without weed.

Within each Block, the two different soil types were randomly allocated so each was represented twice in the four Mainplots in each block. Each mainplot was divided into four Subplots and the species x weed Treatments were allocated again at random within the subplots with the same soil type. Each subplot had six Pots (or seedlings) making a total of 288 pots. The respective layout design is shown in Figure 4.1.

FIGURE 4.1: The layout design of the first glasshouse experiment.



Measurements:

(a) Assessments were made at two-weekly intervals, for 10 weeks after the date seedlings were transplanted (Table 4.5) and the variables measured were: (see Figure III.1 - Appendix III shows the variables measured).

(i) Stem diameter measure was taken from a datum marked above the cotyledons. This was maintained at the same level during the length of the experiment. A "digimatic calliper" graduated in 0.00 mm was used.

(ii) Stem height was measured from the same point as the diameter to the first petiole base. A normal rule graduated in cm was used.

(iii) The number of leaves per seedling on both stem (shoot) and auxiliary shoots were recorded.

(iv) The number of auxiliary shoots was also recorded.

TABLE 4.5: The dates of the assessments made.

ASSESSMENT NO.	DATE	NO. WEEKS AFTER TRANSPLANTING
-	25.09.90	0
1 st	9.10.90	2 weeks
2 nd	24.10.90	4 weeks
3 rd	9.11.90	6 weeks
4 th	26.11.90	8 weeks
5 th	10.12.90	10 weeks

(b) Seedlings were harvested on three occasions to determine biomass (Table 4.6): Seven weeks after transplanting, the leaves, shoots and roots of the eucalypts seedlings and, leaves and roots of the weed were harvested. Two weeks later, only the leaves and shoots of eucalypt seedlings were harvested. The third harvesting was two weeks after that, when the same material was harvested as for the first.

The harvested material was dried in an oven at 60°C for more than one week. The dry-weights were measured using a "Mettler PE 160 balance" graduated in mg.

Hence, all 288 seedlings had three measurements for each variable, 192 seedlings were measured on the fourth measurement and 96 seedlings on the fifth measurement. At each harvest, 48 seedlings (one per subplot) was used for eucalypts roots and the same pot for weed leaves and roots.

TABLE 4.6: The dates of harvestings and respective material collected.

HARVESTING NO.	DATE	No. WEEKS AFTER TRANSPLANT	MATERIAL HARVESTED
-	25.09.90	Transplant	-
1 st	15.11.90	7 weeks	Eucalyptus: leaves, shoots, and roots. Weed: leaves and roots.
2 nd	28.11.90	9 weeks	Eucalyptus: leaves and shoots.
3 rd	10.12.90	11 weeks	Eucalyptus: leaves, shoots, and roots. Weed: leaves, roots.

(c) To quantify the differences between the soil mixtures, they were analysed for N, P, K, Ca, Mg, pH (Table 4.7) and the water holding capacity determined. The sandy soil had a total moisture content of 4.7% and the clay soil 7.2% of the respective oven-dry soil. The formula (Corbett, 1969) used to calculate the total moisture content was:

$$\text{Total moisture content (\%)} = \frac{\text{weight of wet soil(*)} - \text{weight of dry soil(**)}}{\text{weight of dry soil}} \times 100$$

(*) Wet soil after saturating the soil and maintaining it covered for 48 hours.

(**) The soil was oven-dried at 105º C for 48 hours.

TABLE 4.7: **The chemical element content in the two types of soils.**

SOIL TYPE	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	pH
SANDY	118.03	96.63	2321.06	1427.23	1931.69	6.22
CLAY	180.88	110.39	2753.60	1413.26	1692.04	5.80

The data analysis:

Because the treatments were allocated at random in mainplots they were not distributed equally (see Figure 4.1): For example, in Block 1 and Mainplot 4, *E.camaldulensis* occurred three times and *E.grandis* only once, and weed occured three times and non-weed only once. Hence, the difference in performance of the two species of *Eucalyptus* (a fixed effect) cannot be separated from the random effect due to variation between mainplots. The experiment cannot be analysed in this form.

To overcome this problem, mainplots of the same soil type (within each Block) were grouped together and treated as a unit. When this was done, the new units contained equal numbers of treatments and the design was orthogonal.

The variation between original mainplots, grouped as units, had to be estimated and compared with the estimate of variation between subplots within the mainplot. Unfortunately, in most of the subsequent analysis, the variation between mainplots was much larger than the variation between subplots.

The larger estimate of error was used to evaluate the Variance Ratios (V.R.). Consequently, some main effects and interactions were found to be not significant but might have been so if the design had been correctly formulated.

Separate Analyses of Variance (ANOVA) were performed for each variable measured and each harvesting. As all included the same information, only the fifth assessment and the third harvesting were used to summarize the results. The ANOVA was carried out using GENSTAT 5 (Payne *et al.*, 1987). The structure of the ANOVA is detailed in Table 4.8.

TABLE 4.8: **The structure of the Anova with the source of variation and the degrees of freedom (d.f.).**

SOURCE OF VARIATION	d.f.
block stratum	2
block. soil stratum	
soil	1
Residual	2
block. soil. newplot stratum	
species	1
provenances	1
weed	1
soil. species	1
soil. provenances	1
species. provenances	1
soil. weed	1
species. weed	1
provenances. weed	1
soil. species. provenances	1
soil. species. weed	1
soil. provenances. weed	1
species. provenances. weed	1
Residual	29 (28*)
block. soil. newplot. pot stratum	48
Total	95 (47**) (46*)

(*) for weed leaves which had 1 missing value

(**) for dry-weights of *Eucalyptus* roots and, weed roots.

4.2.2. The second glasshouse experiment

The experiment was carried out in the Greenhouse at A.N.U., from 11 th June 1991 to 11 th December 1991.

The provenances seed origin:

Five provenances of *E.camaldulensis* from different habitats (Queensland, Western Australia, Northern Territory and Victoria) were selected. The seed sources and origin are presented on Table 4.9 and were supplied by CSIRO (the Petford and Lake Albacutya provenances are also described in the first glasshouse experiment). As in the first glasshouse experiment, "Victorian rye grass" was the weed used here.

Seedling production:

(a) Seeds were sown on the 11 th June 1991 on germination trays filled with vermiculite and perlite (1:2). The amount of seeds sown according to the number of seedlings needed for the experiment is presented on Table 4.10.

The germination trays were watered before and after sowing. They were maintained in the glasshouse under an automatic watering system till the time of pricking-out.

Provenances started to germinate on the 20 th June 1991. The first to germinate were Petford, Gilbert River and Lake Albacutya. Victoria River and Manning Creek started to germinate two days later (see Table 4.10).

During this stage, "HorticoAquasol" (same mixture as in the first experiment) was applied once a week but at only half strength.

TABLE 4.9: The seed sources and characteristics of the 5 provenances of *E.camaldulensis* used in the experiment.

SPECIES AND SEEDLOT NO.	NO. OF PARENT TREES	LOCALITY	ORIGIN			VIABLE SEEDS/ 10 g	QUANT g
			LATIT. deg	LONG. deg	ALTIT m		
E.camaldulensis: 14338	129	Region E. of Petford (QLD)	17º 17' S	145º 3' E	500	9800	10
E.camaldulensis: 12963	25	Gilbert River (QLD)	18º 30' S	142º 52' E	250	5120	10
E.camaldulensis: 12347	3	Manning Ck W Gibb rv. (WA)	16º 41'S	125º 55' E	460	3900	10
E.camaldulensis: 13941	5	Victoria River (NT)	16º 20' S	131º 7' E	100		10
E.camaldulensis: 15027	12	Lake Albacutya (VIC)	35º 48' S	141º 58' E	70	4133	10

* pretreatment not required prior to sowing.

TABLE 4.10: The quantity of seeds sown per provenances, germination dates and final number of seedlings produced in the second experiment.

PROVENANCES	TOTAL SEEDLINGS NEEDED	TOTAL GRS SOWN	INITIAL DATE OF GERMINATION	No. OF SEEDLINGS	
				PRICKED OUT	PRODUCED
Petford	16	0.11	20.06.91	56	54
Gilbert River	16	0.14	20.06.91	56	43
Lake Albacutya	16	0.18	20.06.91	56	50
Victoria River	16	0.43	22.06.91	56	54
Manning Creek	16	0.14	22.06.91	56	48

(b) A total of 56 seedlings per provenance were pricked-out on the 4 th and 5 th July 1991 to small pots 5 cm in diameter and 6.5 cm deep filled with the same media mixture used in the first glasshouse experiment.

The small pots were moved to glasshouse no.5 (North) where they remained till being transplanted to bigger pots. The photoperiod was extended for 6 hours per day by using artificial light during the periods 5^{00} to 7^{00} am. and 5^{00} to 9^{00} pm. Watering was carried out twice a day.

One week later, seedlings of all provenances started to produce the second pair of leaves. At this stage, Petford seedlings were better developed.

One month later (9 th Aug 1991), all provenances (with 4 and 5 pairs of leaves) showed evidence of a "powdery mildew" (*Oidium spp.*) attack, and so the fungicide BENLATE[3] was applied at a concentration of 1g/litre of water.

3 Benlate is a wettable powder fungicide with an active constituent of 500 gr/Kg of Benomyl.

(c) 80 hard polethylene black pots 24.5 cm in diameter and 24 cm deep were filled with 3 parts of sand and 1 part of clay, from 26 th to 29 th Aug 1991. They were watered to the field capacity.

1.3 gr of the "Victorian rye grass" seeds were sown on the 30 th Aug 1991 in the pots with the "weed" treatment. The weeds started to germinate on the 4 th Sept 1991.

On the 6 th Sept 1991 the classification of the seedlings by height sizes was effected. The heights' means and respective standard errors (s.e.) of the 16 seedlings per provenances that were transplanted were as follows:

PROVENANCES	HEIGHT MEAN (cm)	s.e.
Petford	19.3	1.5
Victoria River	17.3	1.1
Gilbert River	17.6	1.7
Manning Creek	19.1	1.2
Lake Albacutya	18.8	1.6

All the seedlings were transplanted on the 9 th Sept 1991. Provenances were allocated according to the layout of the experimental design (Figure 4.2).

The pots were well-watered before and after transplanting took place. Since the sowing of the weeds to the stage that the water treatment started, watering was carried out twice a day.

(d) Two days before transplantation, the seedlings showed evidence of being attacked by a caterpillar. The insecticide "CARBARYL"[4] was applied. The same insecticide had to be applied twice later, on the 23 rd Sept and 22 nd October 1991.

To prevent attack of "White-fly", between transplanting and harvesting, seedlings were sprayed with the systematic insecticide "ROGOR"[5], on the 13 th Sept, 4 th and 25 th October 1991.

(e) The glasshouses conditions throughout the experiment are shown on Table 4.11.

<u>TABLE 4.11:</u> The glasshouses' conditions with the mean temperatures during the period of the second experiment.

MONTH	MINIMAL TEMPERAT. 0º C	MAXIMAL TEMPERAT. 0º C
JUNE	14.0	21.0
JULY	12.6	27.3
AUGUST	14.6	28.3
SEPTEMBER	15.1	30.0
SEPTEMBER	9.9	23.6
OCTOBER	19.8	29.8
NOVEMBER	20.9	32.3
DECEMBER	21.5	33.5

4 The active constituent of this insecticide is 800 gr/kg of <u>Carbaryl</u>. A mixture of 1 gr of the product in 1 litre of water was used.

5 The active constituent is 300 gr/l of <u>Dimethoate</u> (an anticholinesterase compound) and a mixture of 12 ml of the product in 10 l of water was used.

The experiment design and layout:

A split plot design with 5x2x2 and 4 replicates with a total of 80 seedlings was used (Figure 4.2). There were 20 treatments' combinations allocated in four Blocks. They were:

(i) Five provenances of *E.camaldulensis*: Petford, Victoria River, Gilbert River, Manning Creek and Lake Albacutya;

(ii) Presence or absence of weeds;

(iii) Two levels of water: high and low.

Within Blocks, the combination of weed and water level were randomly allocated into four Mainplots. Thus, these combined treatments were:

(i) High water with weed (represented as HY);

(ii) High water, no-weed (HN);

(iii) Low water with weed (LY);

(iv) Low water, no-weed (LN).

Each mainplot was divided into five Plots and the five provenances were allocated at random within the mainplot. Each plot had only one Pot (or seedling), making a total of 80 plots. So, 16 seedlings per provenance was used.

FIGURE 4.2.: **The layout of the experimental design for the second glasshouse experiment:**

Block						Treatment
BLOCK I	2	3	1	5	4	H Y
	3	4	5	1	2	L Y
	5	3	2	1	4	H N
	4	3	2	5	1	L N
BLOCK II	2	4	3	1	5	L N
	1	3	4	2	5	H Y
	4	1	3	5	2	H N
	3	4	1	5	2	L Y
BLOCK III	2	1	4	5	3	H N
	2	3	1	5	4	H Y
	2	5	1	4	3	L Y
	3	1	2	4	5	L N
BLOCK IV	4	5	2	1	3	L Y
	3	5	4	2	1	L N
	3	2	5	1	4	H Y
	4	2	3	1	5	H N

LEGEND:

Provenances:

1. Gilbert river (QLD)
2. Petford (QLD)
3. Manning creek (W.A.)
4. Victoria river (N.T.)
5. Lake Albacutya (VIC.)

Treatments:

H Y ... High water with weed

H N ... High water with no-weed

L Y ... Low water with weed

L N ... Low water with no-weed

The water treatment:

Since watering was one of the treatments of the experiment, the amount of water applied was controlled from 24 th Sept 1991 to the end of the experiment. Thus, watering was carried-out using a 500 ml beaker graduated in 50 ml.

On the day the water treatment started, 500 ml were applied in both high and low water levels. After that, 250 ml of water was applied every day on the high water level pots, whilst 500 ml was applied once a week on the pots with low water level. So, in total, the low water level treatment received approximately only 23.% of that applied on the high water level treatment.

Measurements:

(a) The first measurement was done 9 days after transplanting. Following this, five assessments more were effected at two weekly intervals.

As in the first experiment, assessments were made for height, diameter, number of leaves on shoots, number of leaves on axillary shoots, number of axillary shoots, and number of shedding leaves. Additionally, leaf size (both length and width) was recorded from the third assessment (i.e., approximately one month after transplanting): The <u>leaf length</u> and <u>leaf width</u> were recorded by selecting and marking two representative leaves of each seedling: the <u>leaf length</u>, in cm, as the distance from the base to the tips of the blade, and the <u>leaf width</u>, in cm, as the widest distance between two points of the margin of the blade in a right angle to the mid-rib. The same leaves were measured throughout the experiment. (see Figure III.1-Appendix III).

(b) Harvesting was carried out 2.5 months after transplanting. All eucalypt leaves, shoots and roots, and the weed leaves and roots were collected and dried in an oven at 60ºC for approximately one week.

(c) Dry-weights of the material collected were then measured. A "Mettler PE 160 balance" graduate in mg was used.

(d) New variables were constructed out of the measured variables. They were:

(i) Euc.No. of total leaves = No. leaves on euc.shoots + No.leaves on euc.axillary shoots

(ii) $$\text{Euc.Leaf length} = \frac{\text{euc.leaf length1} + \text{euc.leaf length2}}{2}$$

(iii) $$\text{Euc.Leaf width} = \frac{\text{euc.leaf width1} + \text{euc.leaf width2}}{2}$$

(iv) Euc.Total dry-weight = euc.leaf dry-wgt + euc.shoots dry-wgt + euc.roots dry-wgt

(v) $$\text{Euc. Root:Shoot ratio} = \frac{\text{euc.roots dry-wgt}}{\text{euc.leaf dry-wgt} + \text{euc.shoot dry-wgt}}$$

(vi) $$\text{Euc. Leaf:Total ratio} = \frac{\text{euc.leaf dry-wgt}}{\text{euc.total dry-wgt}}$$

(vii) $$\text{Euc. Shoot:Total ratio} = \frac{\text{euc.shoot dry-wgt}}{\text{euc.total dry-wgt}}$$

(viii) $$\text{Euc. Root:Total ratio} = \frac{\text{euc.root dry-wgt}}{\text{euc.total dry-wgt}}$$

(ix) Weed Total dry-weight = weed leaves dry-wgt + weed roots dry-wgt

(x) Weed Root:Total ratio = $\frac{\text{weed root dry-wgt}}{\text{weed total dry-wgt}}$

(xi) Weed Leaf:Total ratio = $\frac{\text{weed leaf dry-wgt}}{\text{weed total dry-wgt}}$

The data analysis:

Separate Analysis of Variance (ANOVA) were carried out for all the variables measured and the new variables calculated. The analysis of the sixth assessment and the harvesting were considered for the summary of the results.

The ANOVA was carried out using GENSTAT 5 (Payne *et al.*, 1987), and the LSD test ($P < 0.05$) was used to compare means. The structure of the ANOVA for both assessments and dry-weights was as follows in Table 4.12.

TABLE 4.12: The structure of the ANOVA showing the source of variation and degrees of freedom (d.f.) for the second glasshouse experiment.

SOURCE OF VARIATION	d.f.
reps stratum	3
reps. treatment stratum	
treatment	3
Residual	9
reps. treatm. proven. stratum	
provenance	4
treatment. provenance	12
Residual	48 (47*)
Total	79 (78*)

* **The eucalypts ' leaf size (both length and width) had 1 missing value.**

4.3. RESULTS

4.3.1. Results of the first glasshouse experiment

Analysis of the data:

The ANOVA table for the significant main effects and interactions (at $P < 0.05$) is presented on Tables 4.13 and 4.14 for the size and dry-weights of the eucalypt seedlings and weeds, respectively. The critical F value was generally $F_{(1,29)}(0.05) = 4.18$ except for the weed leaves dry-weight which had missing values.

Results:

(i) Growth in the different soils

Overall, seedlings of both *E.camaldulensis* and *E.grandis* (regardless of the provenance) performed better in the clay soil than in the sandy soil. This was observed for both height and diameter (Figure 4.3) and for the number of auxiliary shoots and number of leaves on them (Figure 4.4). Similarly, dry-matter production in all three components (leaves, shoots and roots) was greater on the clay soils (Figure 4.5).

Seedlings in the sandy soil produced more leaves on the main shoot whilst those in the clay soil put more emphasis on development of auxiliary shoots and leaves (Figure 4.4).

Dry weight of weeds (both leaves and roots) also increased significantly on the clay soil (Table 4.15). This tended to be more pronounced (though not significant) when they were growing with both provenances of *E.grandis* (Table 4.16).

TABLE 4.13: **ANOVA table showing the degrees of freedom (d.f.), mean square (M.S.) and variation ratio (V.R.) for the significant main effects and interactions (P <0.05) on the size of *Eucalyptus* seedlings.**

VARIABLE	SOURCE OF VARIATION	d.f.	M.S.	V.R.	LSD
HEIGHT	SOIL	1	3178.60	252.36	1.45
	SPECIES	1	15682.56	232.92	3.35
	WEED	1	2669.15	39.64	3.35
	SPECIES. WEED	1	868.81	12.90	4.74
	SOIL. SPECIES. PROVEN	1	299.63	4.45	6.70
	RESIDUAL	29	67.33		
	TOTAL	95			
DIAMETER	SOIL	1	13.02	16.63	0.36
	SPECIES	1	7.66	17.51	0.27
	WEED	1	12.20	27.88	0.27
	SOIL. SPECIES. PROVEN	1	1.90	4.34	0.54
	RESIDUAL	29			
	TOTAL	95			
NUMBER OF LEAVES ON SHOOT	SOIL	1	228.17	47.93	0.89
	SPECIES	1	1617.04	109.04	1.57
	WEED	1	266.67	17.98	1.57
	SPECIES. PROVEN	1	77.04	5.19	2.22
	RESIDUAL	29	14.83		
	TOTAL	95			
NUMBER OF AXILLARY SHOOTS	SOIL	1	155.04	163.56	0.40
	SPECIES	1	1633.50	56.04	2.20
	WEED	1	150.00	5.15	2.20
	RESIDUAL	29	29.15		
	TOTAL	95			
NUMBER LEAVES ON AXILLARY SHOOTS	SOIL	1	8232.50	131.57	3.22
	SPECIES	1	102116.30	36.44	21.60
	RESIDUAL	29	2802.16		
	TOTAL	95			

TABLE 4.14: **ANOVA table showing the degrees of freedom (d.f.), mean square (M.S.) and variation ratio (V.R.) for the significant main effects and interactions (P <0.05) on the dry-weights of *Eucalyptus* seedlings and weeds. Numbers of missing values are in brackets.**

VARIABLE	SOURCE OF VARIATION	d.f.	M.S.	V.R.	LSD
1. EUCALYPTUS SEEDLINGS:					
LEAVES DRY-WEIGHT	SOIL	1	59.65	16.75	0.77
	WEED	1	50.70	43.74	0.44
	SPECIES. PROVEN	1	16.66	14.37	0.62
	SOIL. WEED	1	10.31	8.90	0.62
	RESIDUAL	29	1.16		
	TOTAL	95			
SHOOTS DRY-WEIGHT	SOIL	1	34.35	37.01	0.39
	SPECIES	1	5.14	9.55	0.30
	WEED	1	18.26	33.95	0.30
	SOIL. WEED	1	5.75	10.69	0.42
	RESIDUAL	29	0.54		
	TOTAL	95			
ROOTS DRY-WEIGHT	SOIL	1	10.27	91.12	0.19
	WEED	1	19.78	41.36	0.40
	SPECIES. PROVEN	1	2.68	5.60	0.56
	SOIL. WEED	1	4.17	8.72	0.44
	RESIDUAL	29	0.48		
	TOTAL	47			
2. WEED					
ROOTS DRY-WEIGHT	SOIL	1	11.04	13.13	0.53
	RESIDUAL	29	3.06		
	TOTAL	47			
LEAVES DRY-WEIGHT	SOIL	1	25.63	57.84	0.38
	RESIDUAL	28(1)	4.88		
	TOTAL	46(1)			

FIGURE 4.3: The effects of (i) soil and (ii) weed treatments on the height and diameter of provenances of *E.grandis* and *E.camaldulensis* seedlings. (See list of abbreviations for full names of all provenances).

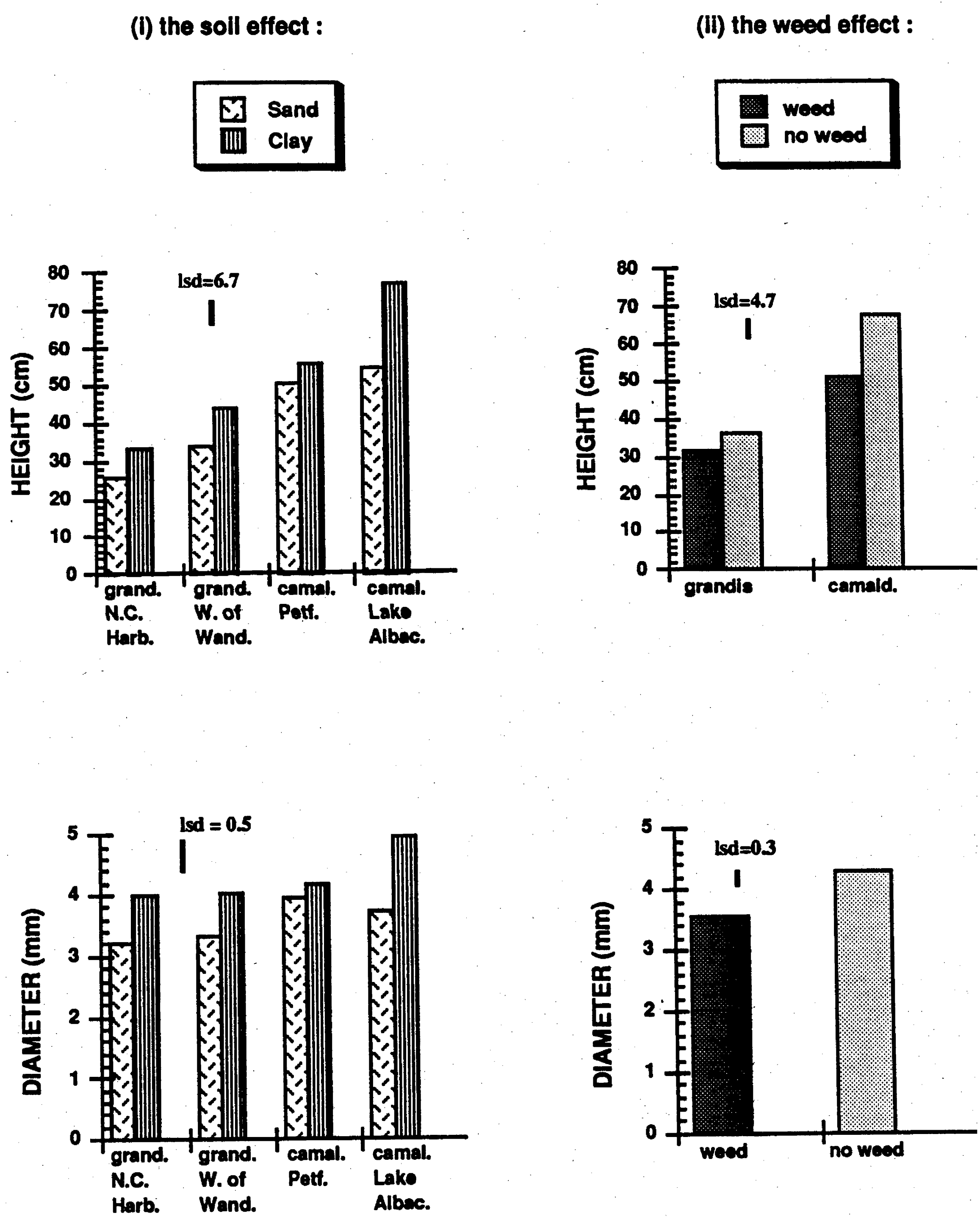
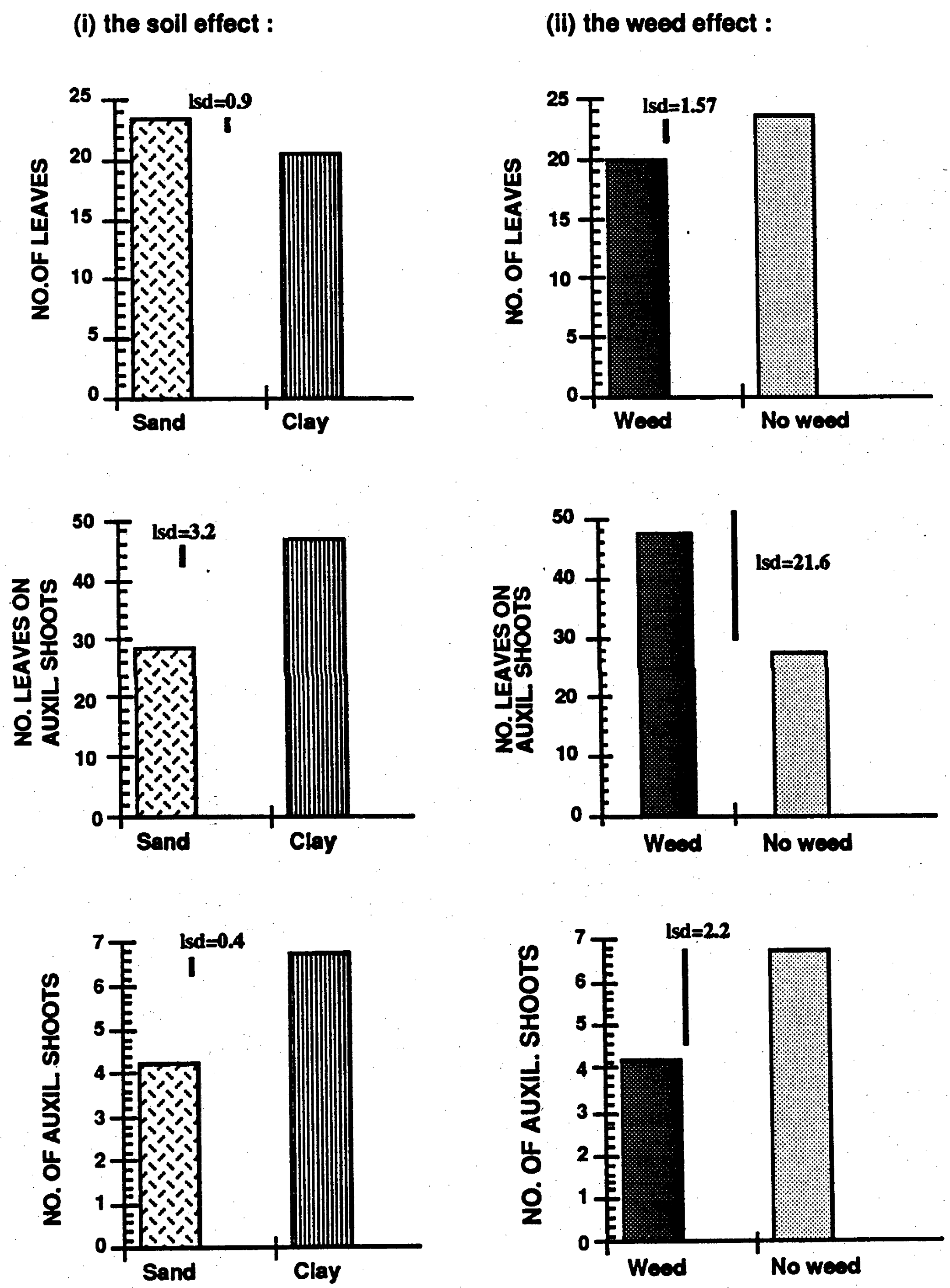
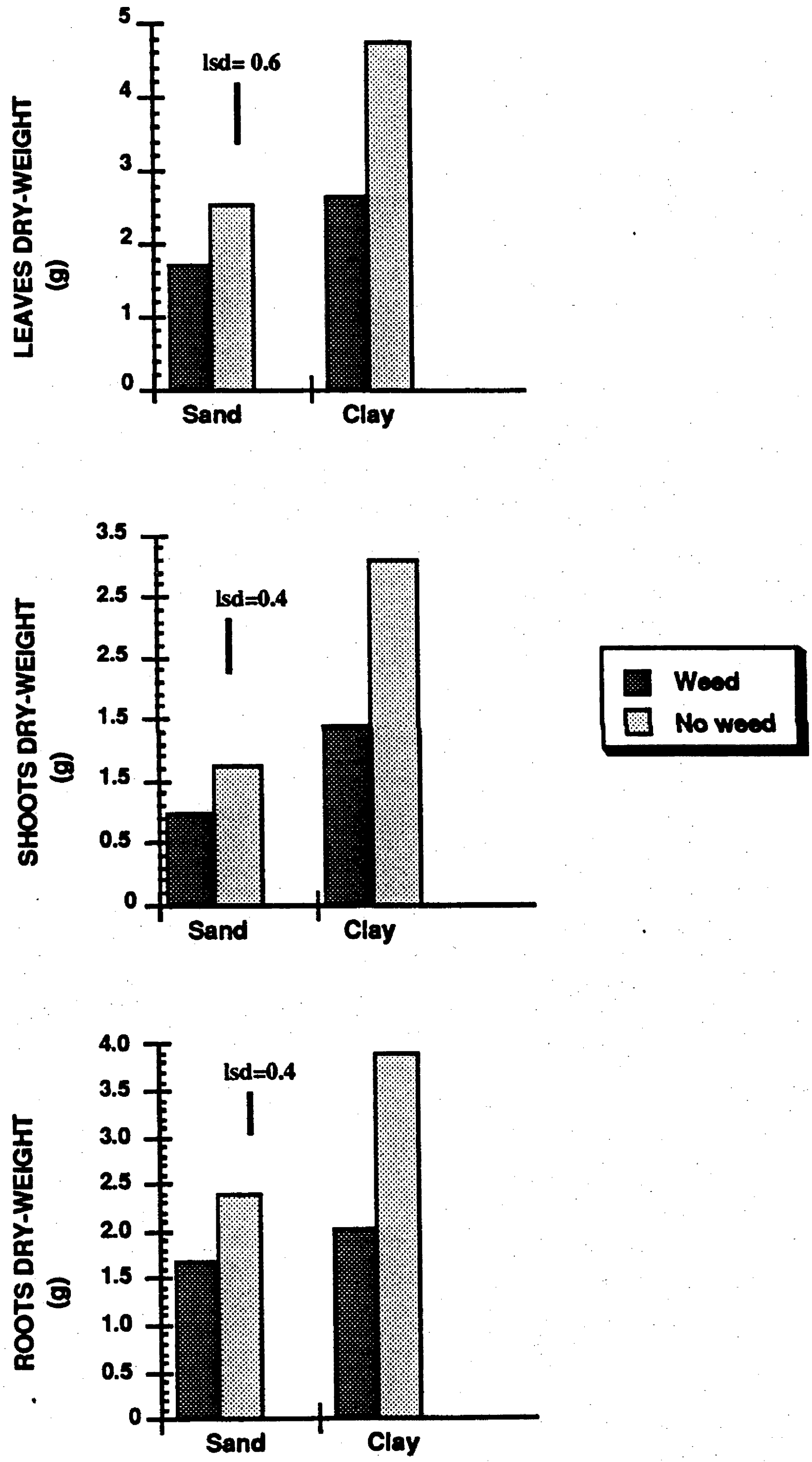


FIGURE 4.4: The effects of (i) soil and (ii) weed treatments on the number of leaves on the main shoots, the number of leaves on axillary shoots and the number of axillary shoots of *Eucalyptus* seedlings.



<u>FIGURE 4.5:</u> **The soil x weed interaction on the dry-weights of leaves, shoots and roots of *Eucalyptus* seedlings.**



<u>TABLE 4.15:</u> **The soil main effect on the dry-matter production (g) of the two components (leaves and roots) of weeds.**

COMPONENTS	TYPES OF SOIL		LSD
	SANDY	CLAY	
LEAVES	1.22	2.68	0.38
ROOTS	1.12	2.08	0.53

<u>TABLE 4.16:</u> **The effect of soil type on dry-matter production of weeds (g) when they are growing under different *Eucalyptus* species and provenances.**

SPECIES/PROVENANCES	LEAF DRY-WGT		ROOT DRY-WGT	
	SAND	CLAY	SAND	CLAY
<u>E.camaldulensis:</u>				
PETFORD	1.14	2.32	1.27	1.78
LAKE ALBACUTYA	1.01	1.96	1.06	1.65
<u>E.grandis:</u>				
N.COFFS HARBOUR	1.27	3.22	1.33	2.50
W. WANDECLA	1.46	3.22	0.81	2.37

(ii) The effect of weeds

Weeds reduced growth (both height and diameter) of eucalypt seedlings (Figure 4.3). The number of leaves on the main shoot and the number of axillary shoots were also significantly reduced in presence of weeds (Figure 4.4).

Generally dry-weights decreased considerably in presence of weeds. This was very pronounced in the clay soil but not significant in the sandy soil for the seedlings' shoot dry weights (Figure 4.5).

(iii) Species and provenances differences

There were clear differences in height and diameter growth between species and between provenances. Overall, provenances of *E.camaldulensis* were significant taller than *E.grandis* provenances. This was so in both soil types whether weeds were present or not (Figure 4.3).

A significant interaction with provenance x soil type was observed for height and diameter, with *E.camaldulensis* from Lake Albacutya, which was bigger than the others when grown in clay soil but not in sandy soil (Figure 4.3). For *E.grandis*, the provenance from W. of Wandecla was taller than N. Coffs Harbour.

These differences were reflected in the dry-weight data. Shoot dry-weight production in *E.camaldulensis* was greater than in *E.grandis*. Leaf and root dry-weights production of the material from Petford also tended to be superior to *E.grandis* but that from Lake Albacutya was not (Figure 4.6).

The two eucalypt species differed in the number of leaves on both main shoots and axillary shoots as well as in the number of axillary shoots (Figure 4.7). Provenances of *E.camaldulensis* produced more leaves on the main shoots (where Lake Albacutya had noticeably more leaves) whereas provenances of *E.grandis* produced many more axillary shoots and consequently put more leaves on these.

FIGURE 4.6: **Differences in the shoot, leaf and root dry-weights between seedlings of the species and provenances of *Eucalyptus*.**

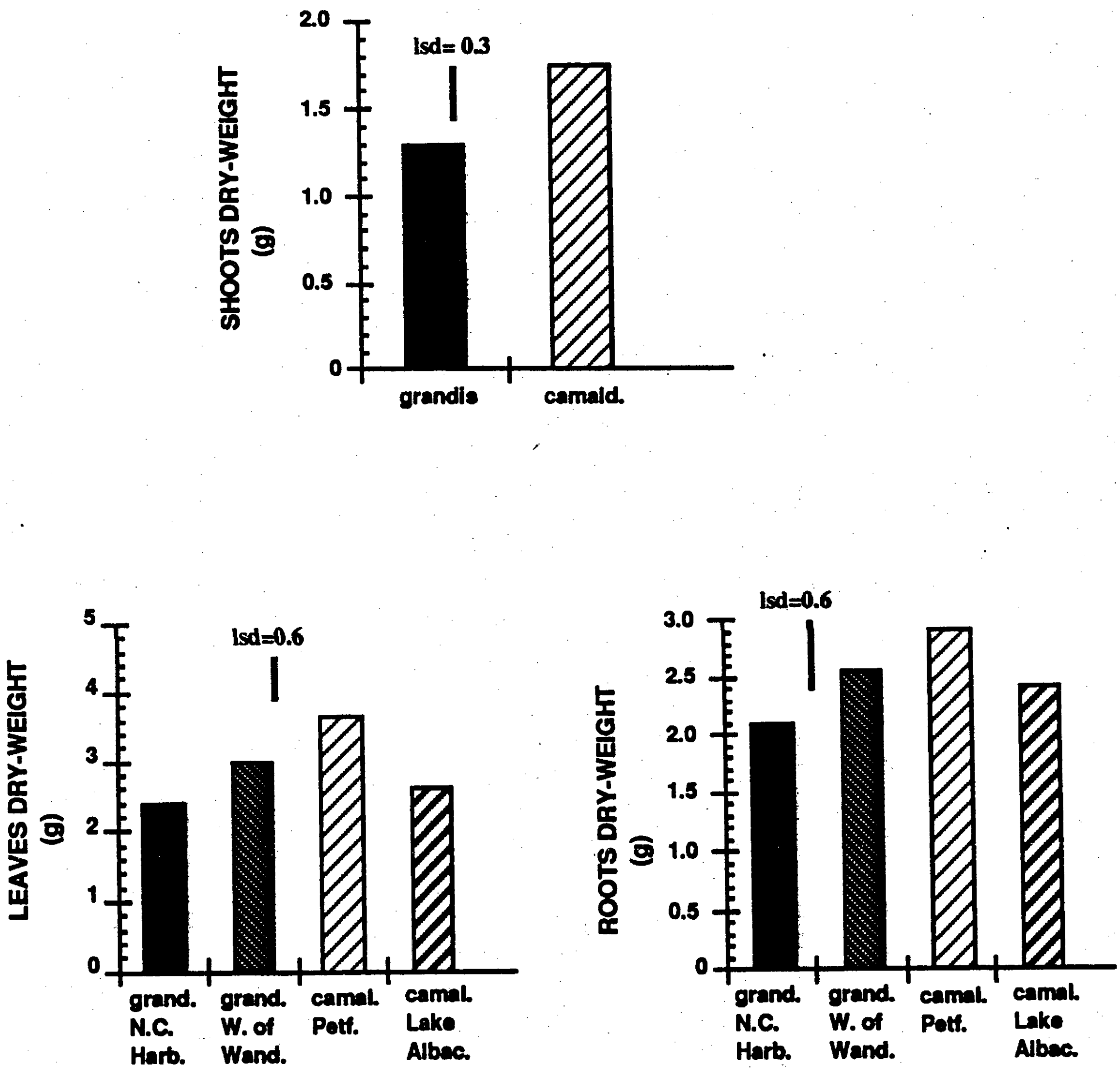
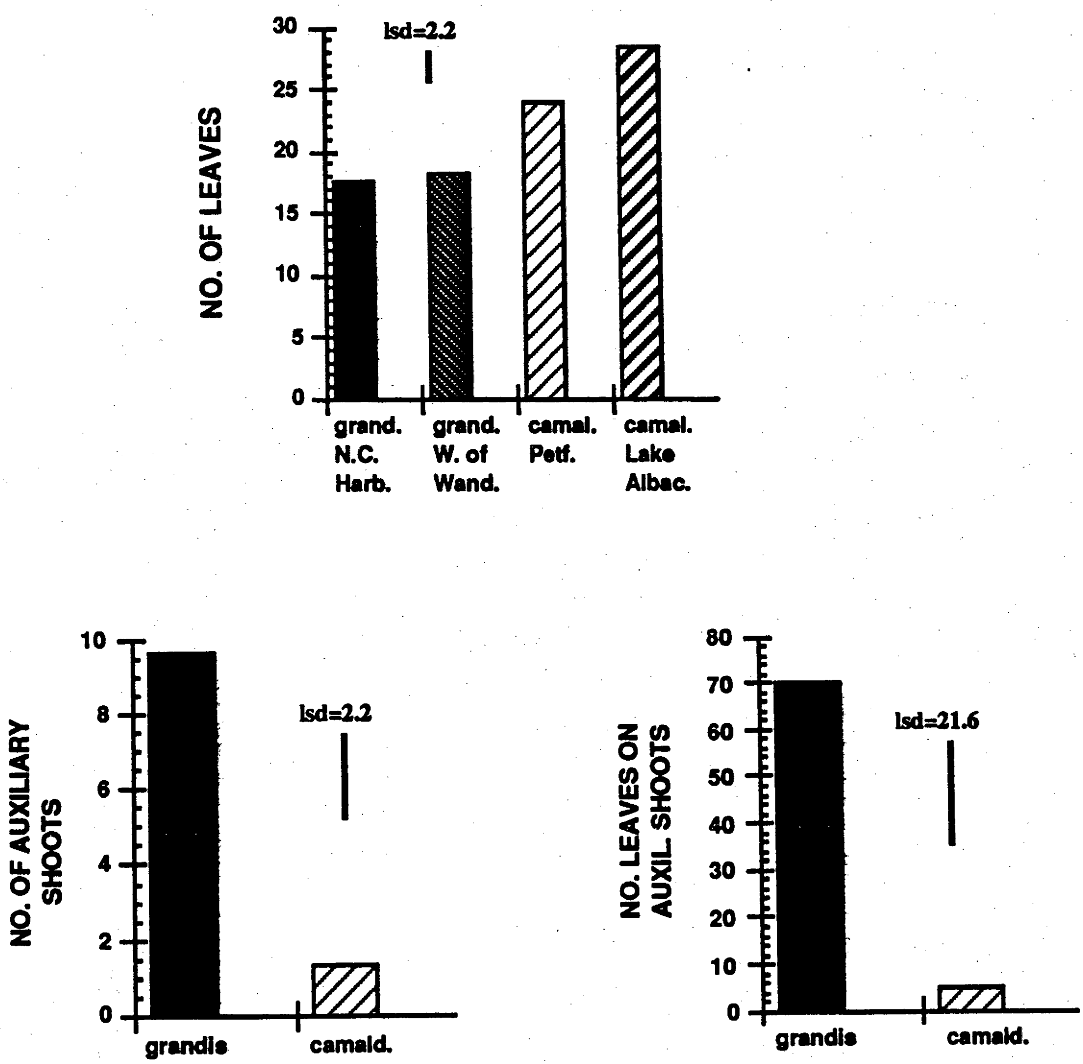


FIGURE 4.7: **Differences between seedlings of *Eucalyptus* species and provenances in the number of leaves on the shoots and axillary shoots and, the number of axillary shoots.**



4.3.2. Results of the second glasshouse experiment

Analysis of the data:

The analysis of variance of the sixth measurement and dry weights of *Eucalyptus* seedlings showed significant terms at P< 0.05 at the treatment and provenance main effects for most of the variables (Table 4.17). No significant interactions were observed except for the length of the leaves with a slightly significant term at P< 0.05. In relation to weeds, the treatment main effect was significant at P< 0.001 (Table 4.17). (Detailed table of ANOVA is shown in Table IV.1 - Appendix IV).

TABLE 4.17: **ANOVA showing the mean square (M.S.) and the significance terms at the treatment level (with 3 degees of freedom) and provenance level (with 4 degees of freedom) at 5% level (*), 1% level (**), 0.1% level (***) and not significant (n.s.) for all the variables measured on the 22nd Nov. 1991 - the sixth measurement.**

VARIABLE	TREATMENT		PROVENANCE	
	M.S.	SIGN.LEVEL	M.S.	SIGN.LEVEL
Size of Euc. seedlings:				
Height	513.01	**	917.35	***
Diameter (Ln)	0.06	**	0.07	***
No. Dropped Leaves (Ln)	0.47	**	0.05	n.s.
Leaf length	78.68	***	19.64	***
Leaf width	2.77	**	1.59	***
No. Total Leaves (Ln)	0.44	**	0.41	***
Dry-weights of Euc.:				
Leaves	6.22	***	0.32	n.s.
Stem	0.74	**	0.64	***
Roots	9.19	***	0.81	n.s.
Total dry-weight	39.71	***	0.81	n.s.
Root:Shoot ratio	0.10	*	0.17	**
Leaf:Total ratio	0.00	n.s.	0.00	n.s.
Stem:Total ratio	0.00	*	0.02	***
Root:Total ratio	0.01	*	0.02	***
Dry-weights of Weed:				
Leaves	35.57	***	0.05	n.s.
Roots	80.71	***	0.17	n.s.
Total	223.40	***	0,40	n.s.

Results:

(i) Growth affected by weeds and water regime

In the second study the presence of weeds significantly reduced seedling size, especially height (Figure 4.8) and dry matter production (Figure 4.9) in *Eucalyptus*. It also reduced leaf size (Figure 4.8). However a reduction in diameter growth and in the number of leaves in presence of the weeds was only obvious in the low water regime (Figure 4.8).

The low water regime alone generally had little effect. There was no effect when no weed was present (except for the number of dropped leaves) and even in the presence of weed, the low water regime only affected diameter and the number of leaves produced (Figure 4.8).

However, low water did affect the proportion of dry matter allocated to the different seedling components (Figure 4.9). With the low water regime the proportion of dry matter allocated to the stem increased and that allocated to the roots decreased accordingly. There was no effect observed on the allocation of dry matter to the leaves; consequently, the root:shoot ratio was reduced in the low water regime (Figure 4.9).

Production of weed dry matter (both leaves and roots) was also reduced with the low watering regime (Table 4.18). It seems that this reduction, due to low water, varies with the *E.camaldulensis* provenances (Table 4.19), even though there was no statistical significance (Table IV.1-Appendix IV). For example, the leaf dry weight of the weeds was not affected by the water availability when growing with the Manning Creek provenance and the reduction on weed root dry weight was least with the Petford provenance.

FIGURE 4.8: **The effects of water and weed on the size of seedlings of *E.camaldulensis*.**

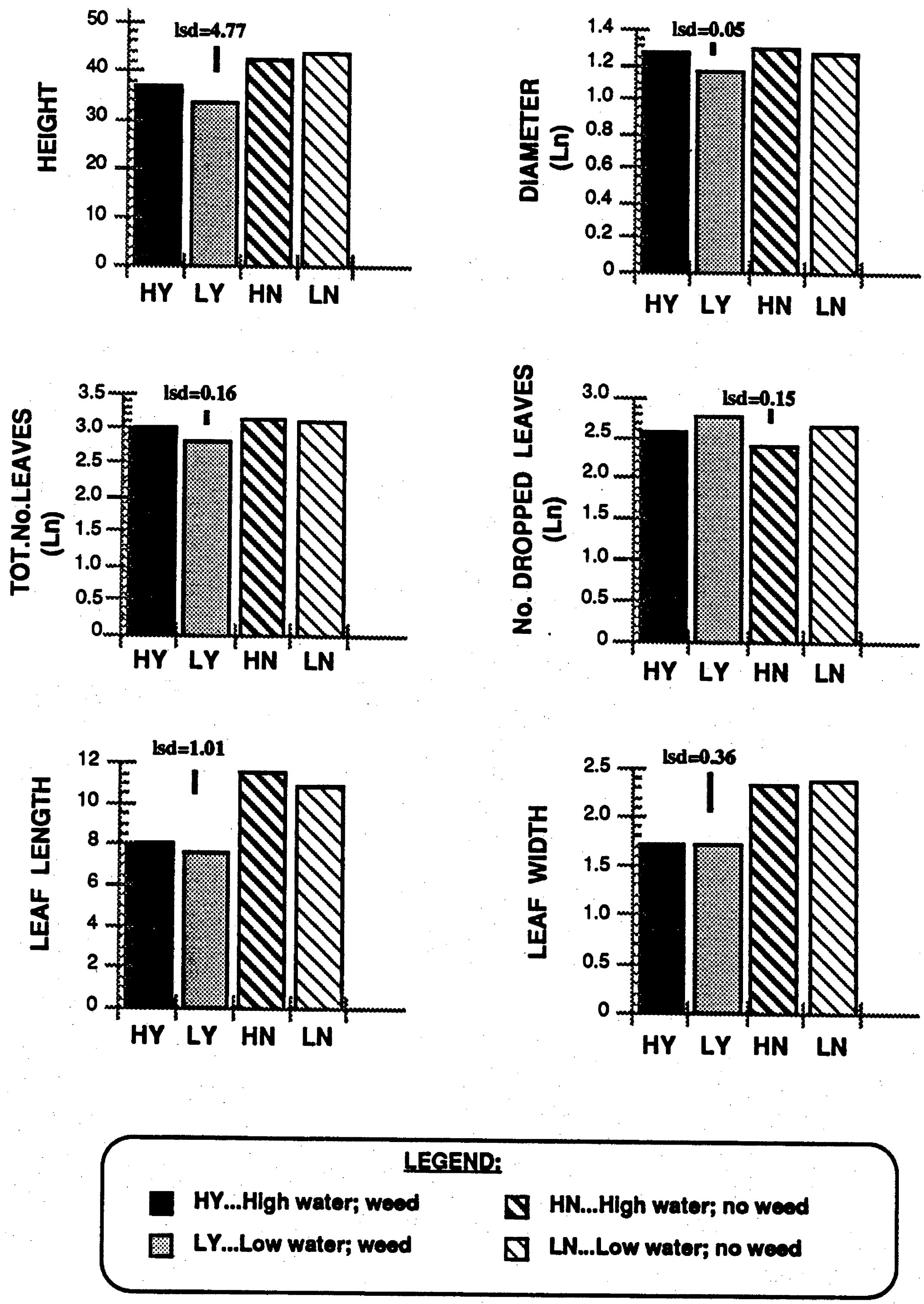


FIGURE 4.9: The effects of water and weed competition on the dry matter production (g) of seedlings of *E.camaldulensis*.

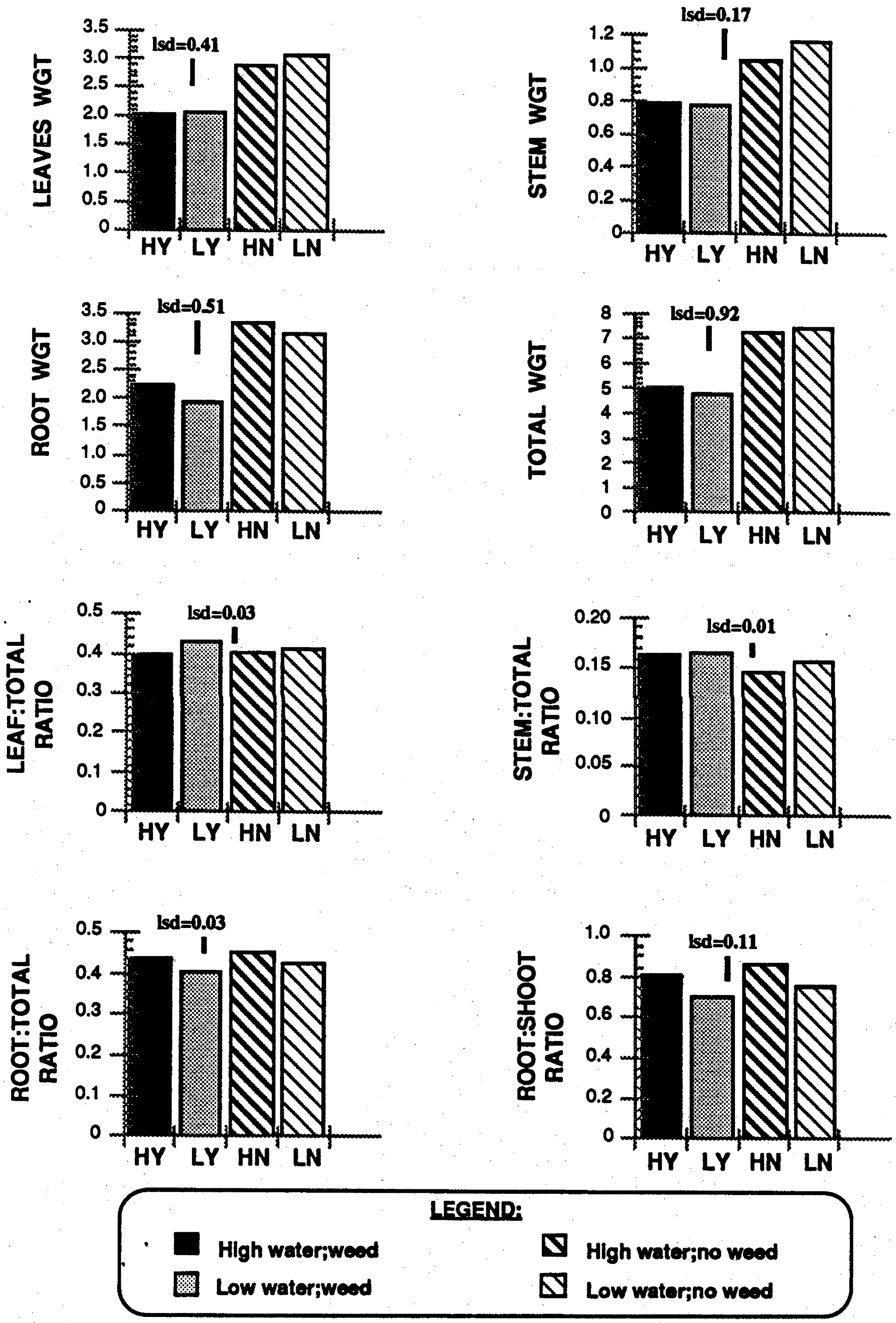


TABLE 4.18: **The effect of water level on dry-matter production (g) of weeds.**

COMPONENTS	WATERING LEVEL		LSD
	HIGH WATER	LOW WATER	
LEAVES	2.45	2.15	0.16
ROOTS	3.74	3.17	0.33
TOTAL	6.19	5.32	0.48

TABLE 4.19: **The effect of water level on dry-weight of weeds (g) when growing along side of the five different provenances of *E.camaldulensis*.**

PROVENANCES	LEAVES		ROOTS	
	HIGH WATER	LOW WATER	HIGH WATER	LOW WATER
LAKE ALBACUTYA	2.52	2.20	3.98	3.34
PETFORD	2.58	2.22	3.77	3.48
GILBERT RIVER	2.51	2.15	3.70	3.27
MANNING CREEK	2.12	2.12	3.53	2.80
VICTORIA RIVER	2.47	2.06	3.73	2.97

(ii) The provenance differences

There were clear differences between the *E.camaldulensis* provenances in height, diameter, leaf size and total number of leaves (Figure 4.10). There were also provenance differences between their stem dry-weights but not between their total dry weights (Figure 4.11).

Material from Lake Albacutya (the southern provenance) differed markedly from the northern provenances, but there were also some differences among the latter. The Lake Albacutya provenance was biggest in height and diameter (Figure 4.10), its leaves were numerous but smaller in size (Figure 4.10), it had the biggest stem dry-weight but the lowest root dry-weight (Figure 4.11).

In contrast, the Victoria River provenance was smaller in height (but not in diameter), had longer but fewer leaves (Figure 4.10), a smaller stem dry-weight and bigger root dry-weight than the Lake Albacutya provenance (Figure 4.11). The other three provenances were intermediate, with the Petford the material performing generally better.

The weight of leaves as a proportion of the seedling dry weight did not differ between provenances (Figure 4.11) but the proportion in the stem and roots did (the Lake Albacutya had the biggest stem:total ratio but the lowest root:total ratio). As a result, the root:shoot ratio differed too (the Lake Albacutya having the lowest ratio) (Figure 4.11).

FIGURE 4.10: **Differences in the size of the seedlings of the five provenances of *E.camaldulensis*.**

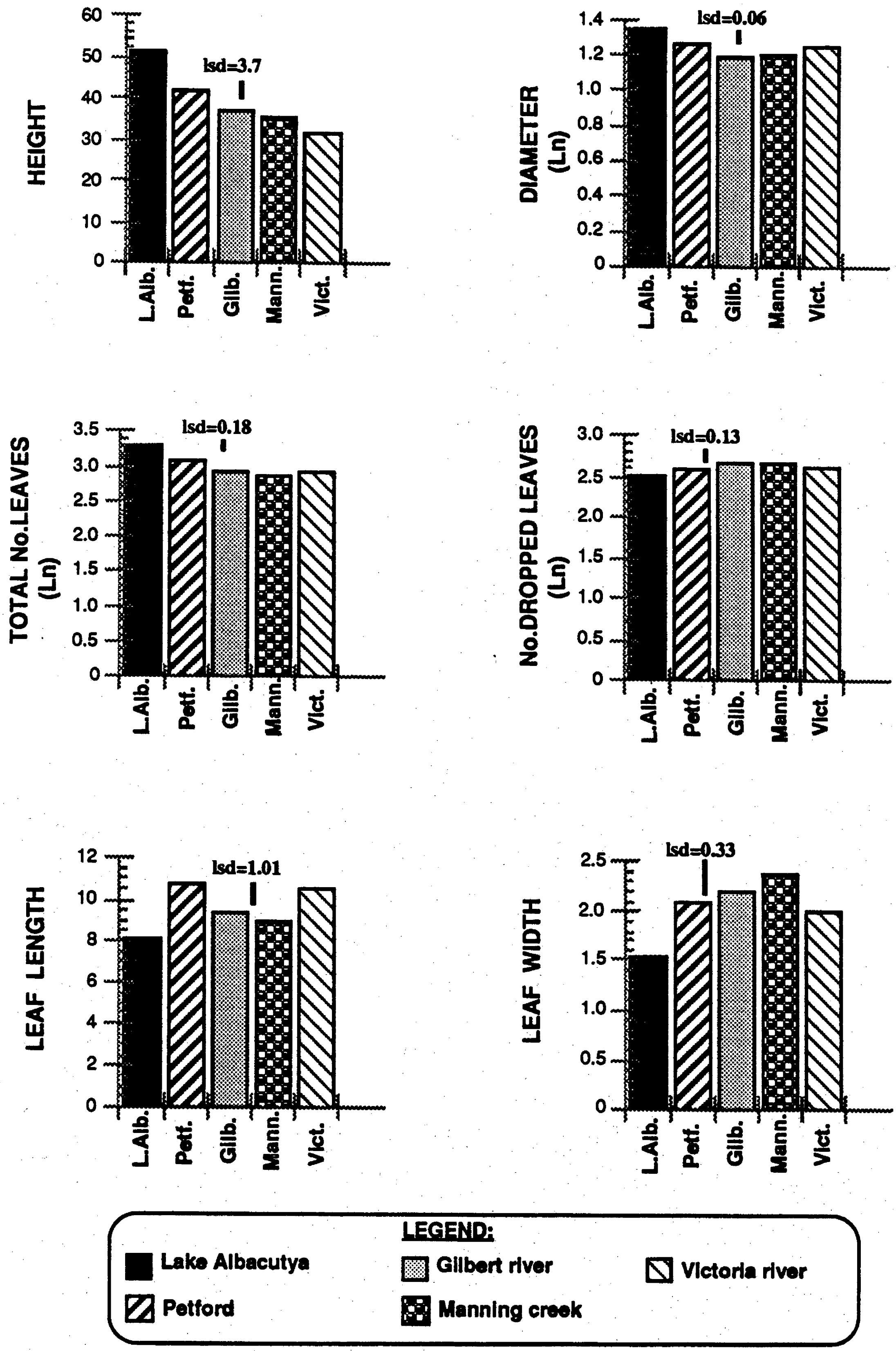
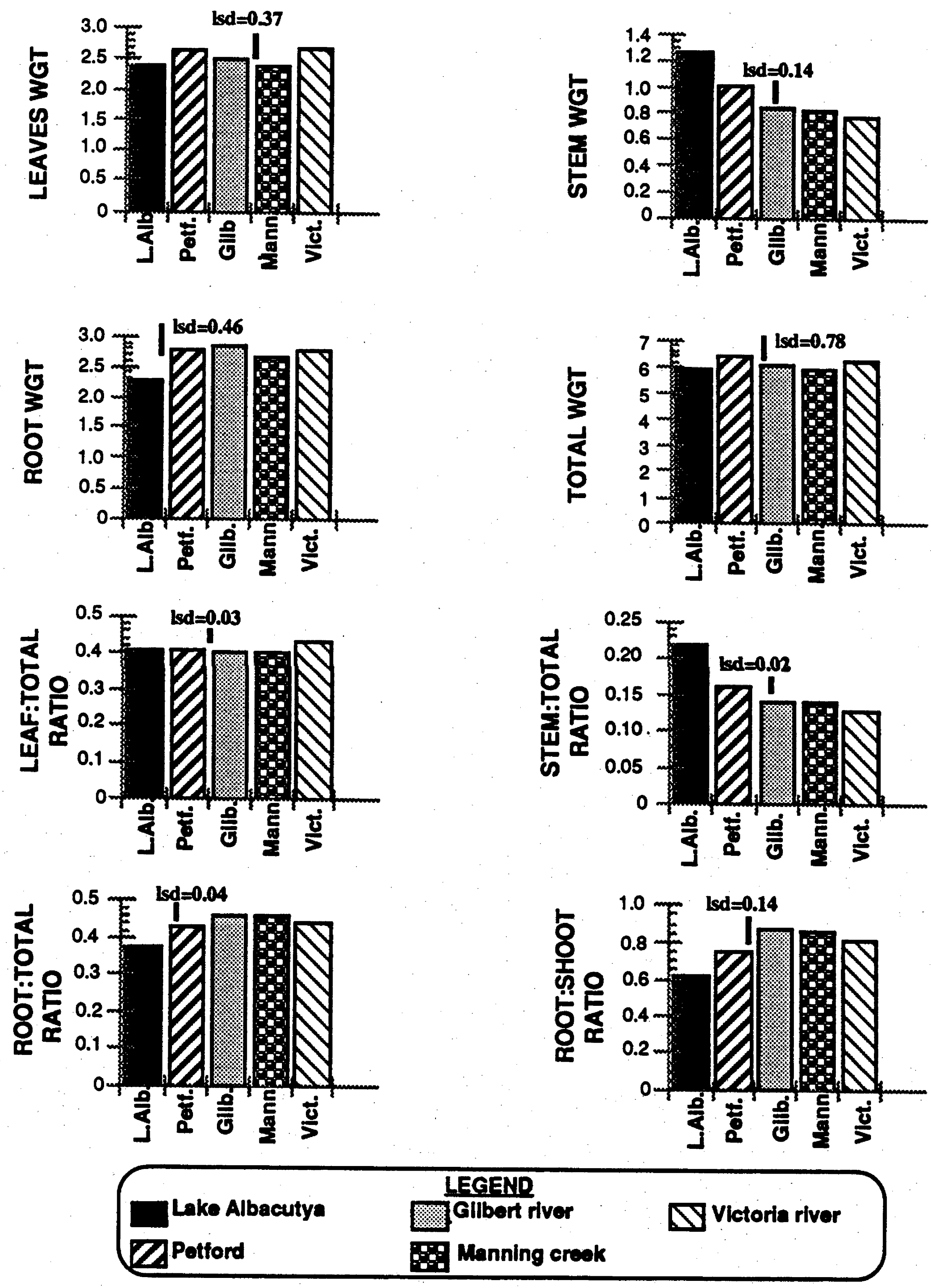


FIGURE 4.11: **Differences in the dry matter production and dry matter allocation in seedlings of the five provenances of *E.camaldulensis*.**



Even though there were no significant provenances x treatment effects (Table IV.1-Appendix IV) some trends were observed. Because these trends may be important in the field conditions, they are here discussed:

•The effect of the weeds on height growth was least in the Petford provenance. The Gilbert River, Manning Creek and Victoria River were the most affected. The weed effect on the Lake Albacutya was marked only in the low water treatment (Figure 4.12).

•There was a reduction in the total number of leaves only when the seedlings were grown in low water in presence of weeds. The effect was least for Petford and Gilbert River provenances and more noticeable for Lake Albacutya, Victoria River and Manning Creek (Figure 4.12).

•Leaf length of all provenances was affected by weeds. However leaf length in the Lake Albacutya material was also affected by the low water regime (Figure 4.12).

•As noted earlier, seedling dry weight was reduced in the presence of weeds. This was true for all five provenances. The only difference was that there was a more marked reduction in the Gilbert River and Victoria River material in the low water regime (Figure 4.13).

• The effect on root:shoot ratios varied with provenances. The material from Petford was not affected by either water or weed treatments (the ratio tended to increase in the low water with weeds present) whilst the Manning Creek, Victoria River and Gilbert River provenances had their ratios decreased markedly with low water and weeds treatments combined. The presence of weeds reduced root:shoot ratio on the Lake Albacutya provenance (Figure 4.13).

FIGURE 4.12: **The effect of water and weeds on the height, total number of leaves and leaf size of the seedlings of the five provenances of *E.camaldulensis*. (see list of abbreviations for full names of the provenances).**

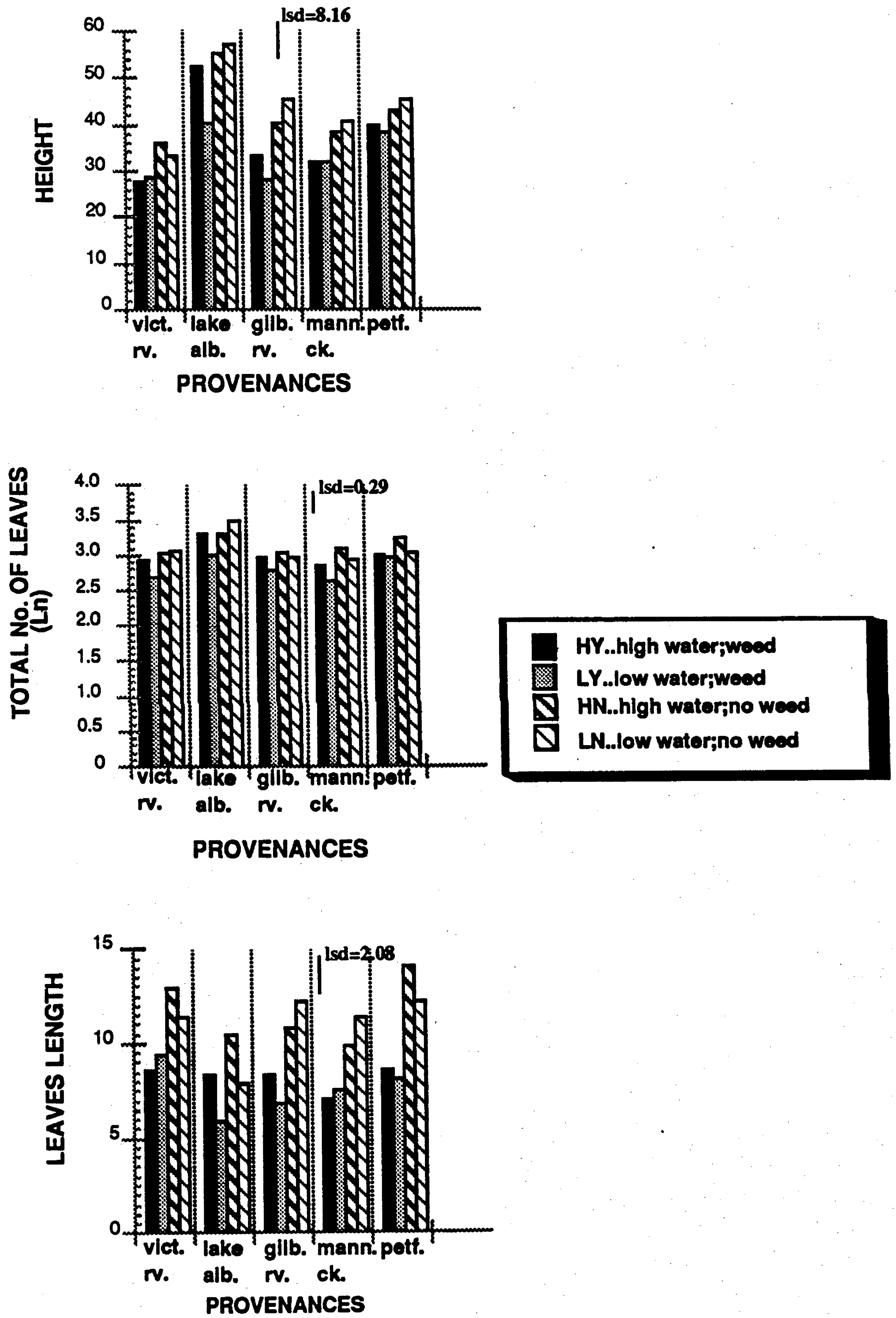
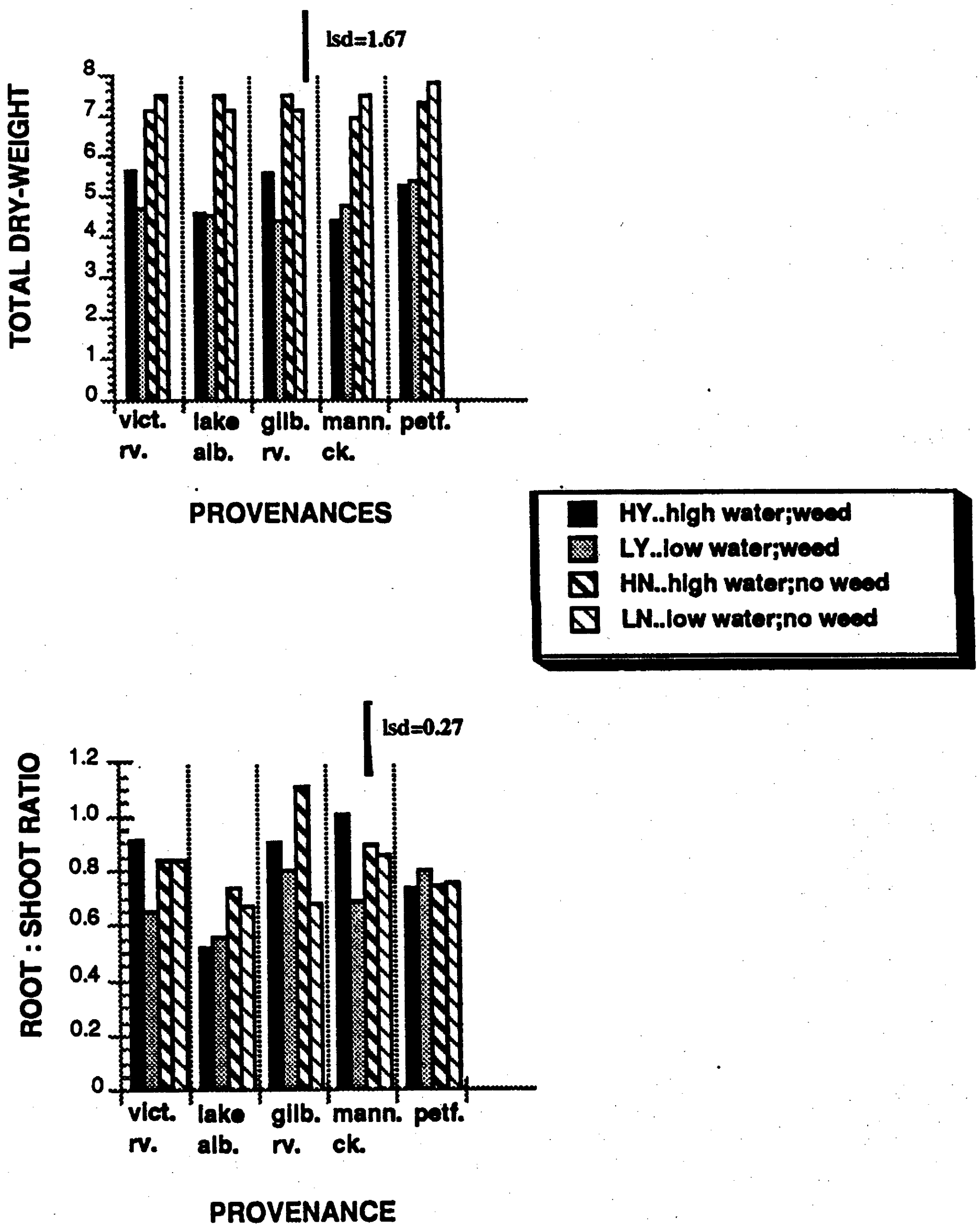


FIGURE 4.13: **The effect of water and weeds on the total dry matter production (g) and root:shoot ratio of the seedlings of the five provenances of *E.camaldulensis* used in the second glasshouse experiment. (see list of abbreviations for full names of the provenances).**



4.4. DISCUSSION

4.4.1. Seedling size

The treatment effects:

(i) Effect of weeds

In both glasshouse experiments, the presence of weeds reduced seedling size (height and diameter) of both *E.grandis* and *E.camaldulensis* (Figures 4.3, and 4.8). This effect occurred regardless of the type of soils (glasshouse-1 - Figure 4.3) and of the water treatments used. The effect was especially evident in height growth (glasshouse-2 - Figure 4.8).

(ii) Effect of water

The experiments examined the importance of water. The low water regime alone was not sufficient to reduce growth of seedlings (Figure 4.8). The low water, in the second experiment, was only 23% of the amount applied on the high water regime but this apparently did not reduce the moisture content of the soil sufficiently to produce significant differences on seedling growth. However, in the first experiment, the lower moisture content of the sandy soil compared to the clay soil (4.7% and 7.2%, respectively) may have affected growth as height and diameter were smaller in the sandy soil (except for *E.camaldulensis* from Petford) (Figure 4.3). The effect of water can also be shown by the decrease in the weeds dry weight produced on the sandy soil (Table 4.15) compared to that in the low water regime (Table 4.18).

The presence of weeds, in the second experiment, increased the differences in growth, presumably by increasing the stress conditions of the seedlings. In doing so, they reduced growth in diameter and further reduced height growth of the seedlings (Figure 4.8).

These findings show water availability is important for seedlings growth and may indicate the detrimental effect of weeds is a result of water competition. This agrees with several studies where competition for water was considered most important (Crafts and Robbins, 1962; Del Moral and Muller, 1970; Squire, 1977; Nambiar and Zed, 1980; Chaney, 1981).

The species and /or provenances differences:

In the first experiment there were clear differences between the two eucalypt species for height growth (Figure 4.3). The results show the supremacy of *E.camaldulensis* seedlings over *E.grandis* in both soil types and regardless of the presence or absence of weeds.

Differences were observed too between provenances of each species for height growth. They were greater on clay soil. In both soil types, the W. of Wandecla provenance of *E.grandis* was greater than the N. Coffs Harbour provenance. The Lake Albacutya provenance of *E.camaldulensis* was taller than the Petford provenance on clay soil but much less so on sandy soil.

However, the results for diameter were less clear-cut with a possible interaction. On clay soil the Lake Albacutya material of *E.camaldulensis* was superior to all other provenances, whilst on the sandy soil, the *E.camaldulensis* Petford provenance was biggest and significantly superior to both provenances of *E.grandis* (Figure 4.3).

In the second glasshouse experiment, provenances of *E.camaldulensis* differed in both height and diameter growth (Figure 4.10). The Lake Albacutya provenance generally performed better than the other four provenances, but this was not so with the low water regime and weeds together. They all had reduced height growth due to weeds (Figure 4.12) but in both Lake Albacutya and Gilbert River provenances it was reduced further with the low water regimes.

The Petford provenance was the least affected by the treatments: either in the first experiment, by soil type and weeds or in the second, by water regime and weeds. This provenance produced similar height and diameter growth in all treatments.

The provenances of *E.camaldulensis* used in these two glasshouse experiments are from different climatic zones:-

(i) From the **humid tropical highland,** the Petford provenance , from a low monsoon zone in the east coast of Queensland, with annual rainfall between 500 - 750 mm in summer, and regular distribution, 5-9 months of growing periods;

(ii) From the **dry tropical inland,** - in N. Queensland, the Gilbert River (irregular rainfall); in the Northern Territory, the Victoria River provenance (irregular rainfall) and; in Western Australia, the Manning Creek (moderate rainfall), - with summer rainfall decreasing from the coast to the inland, 650 mm per year, 5-1 month of growing period;

(iii) From the **temperate inland zone,** the Lake Albacutya provenance, with moderate winter rainfalls of 400 mm per year.

Similarly, the two *E.grandis* provenances used in the study are from two different zones:

(i) The W. of Wandecla provenance, from the **humid tropics,** the same climatic zone as *E.camaldulensis* from Petford;

(ii) The N.Coffs Harbour, from the **warm temperate climate zone,** on the North Coast of New South Wales, with a late summer/early autumn rainfall, 1500 mm per year, being more reliable than winter rainfall.

According to Pallardy (1981) the environment will affect plant morphology and physiology independent of genetic influences. The eucalypts survive, grow and reproduce in such diverse natural habitats that, by natural selection, they possess a wide range of physiological attributes to cope with stress (Awang, 1977; Florence, 1981; Eldridge and Cromer, 1987) and are specifically adapted to the moisture conditions in the environments in which they occur naturally.

Gibson *et al.* (n.d.), in a glasshouse study in Canberra, founded that *E.camaldulensis* seedlings from the humid tropics (Petford and Mt.Carbine) were tallest, those from dry tropics (Katherine and Lennard river) were intermediate in size, with the shortest seedlings being from the semi-arid regions (Tennant Creek and Mt Isa). Pallardy (1981) observed that the slow rate growth (in terms of shoot and leaf surface area) of plants from xeric habitats compared to that from wetter or mesic habitats, reduced the danger of lethal desiccation by extreme atmospheric and soil drought.

Such adaptations could have important consequences for their behaviour when used in plantations outside their natural habitats (Bachelard, 1986; Gibson and Bachelard, 1987). Any slight superiority in growth or physiological characteristics associated with morphological variations shown by one species over others under stress conditions can be advantageous for the survival of the species in a competing situation.

These two studies have shown species and provenance differences in terms of Eucalypt performance are complex. These widespread species exhibit substantial provenance variation and interaction with environmental conditions.

Therefore, a knowledge of such differences is important in the selecting species and/or provenances for a specific site.

4.4.2. The production of leaves

The treatment effect:

The total number of leaves and number of auxiliary shoots of eucalypts seedlings were reduced by weeds (Figures 4.4) being further reduced with the low water regime (Figure 4.8). Leaf size was also reduced by weeds regardless of the water regime (Figure 4.8). Moreover, the results showed that seedlings in the sandy soil produced more leaves on the main shoot and reduced the number of auxiliary shoots and their leaves compared to seedlings on the clay soil (Figure 4.4).

These results agree with many other studies. Yang (1987) found that moisture regimes exert great influence on the size of adult leaves of *E.globulus* and other eucalypt species in the field. The drier the site, the smaller the leaves. This reinforces the comments in the previous section. A large number of leaves implies greater surface area through which water can be lost and, consequently, plants are less adapted to grow under limiting soil moisture conditions (Awang, 1977). Myers and Landsberg (1989) also observed that restricting water supply caused reduction of the total leaf area of two eucalypt species by reducing the number of leaves and the leaf size and thus reduced transpiration.

The ability to use water efficiently when it is available through a combination of low leaf area and high assimilation rate is one way that plants have to tolerate dry periods (Florence, 1981) and the capacity of dropping leaves during periods of prolonged drought is one mechanism of drought avoidance (Eldridge and Cromer, 1987; Gibson *et al.*, 1991). This and the ability to grow with a low leaf surface area will improve water stress tolerance of plants and enable them to conserve water during the dry season.

The species and /or provenances differences:

E.camaldulensis produce more leaves on the main shoot of the seedlings whilst *E.grandis* produce more auxiliary shoots and thus more leaves on auxiliary shoots (Figure 4.7). The two *E.grandis* provenances had similar numbers of leaves but of the provenances of *E.camaldulensis* the Lake Albacutya had a greater number of leaves than the Petford provenance (Figure 4.7). This was confirmed in the second glasshouse experiment with the Lake Albacutya having numerous leaves but smaller in size than the other northern provenances (Figure 4.10).

The presence of weeds reduced the number of leaves in all provenances. However, the effect was not significant for the Petford and Gilbert River material. The Lake Albacutya, Manning Creek and Victoria River provenances reduced the number of leaves in the low water with weeds (Figure 4.12).

According to Florence (1981) eucalypts seem to remain physiologically active and continue to use water under conditions of moderate or severe stress with the capacity of responding quickly to watering. They produce naked buds which stay dormant during stress and when moisture permits the meristimatic tissue is activated and prolific epicormic shoots with leaves develop (Eldridge and Cromer, 1987). This suggests that *E.grandis* may be more susceptible to long periods of stress due to the great amount of axillary shoots and leaves that its seedlings bear.

The reduced number of leaves presented by the northern provenances in relation to Lake Albacutya was also noticed by Awe (1973) and again suggests selection for reduced leaf surface area under drier environmental conditions.

Gibson *et al.* (n.d.) observed that leaf area of *E.camaldulensis* seedlings from semi-arid zone was lower than that of tropical monsoon seedlings: seedlings from the humid tropics (Petford) had the broadest leaves and the ones from the semi-arid zone (Tennant Creek) had narrow leaves whereas seedlings from the dry tropics (Katherine) were intermediate in leaf characteristics.

4.4.3. Dry matter production

The treatment effects:

In the first experiment, the presence of weeds reduced dry-weight of the seedlings of *E.grandis* and *E.camaldulensis* (Figure 4.5). Reduction of biomass production due to weeds was greater on the clay soil, despite its more favourable moisture status (Figure 4.5). This might be explained by more dry matter production and more effective competition from weeds on this soil (Table 4.15).

However, the presence of weeds on the sandy soil also reduced dry matter production of the seedlings. As noted when discussing the effect recorded for height growth in the second experiment, the lower water level alone did not produce enough stress to affect biomass production of the seedlings (Figure 4.9).

These results can be compared with other studies. Moisture stress not only affects plant growth (Awang, 1977; Gwaze, 1990; Gibson *et al.*, 1991) but profoundly influences root growth (Sutton, 1969; Awang, 1977; Ritchie and Dunlap, 1980). Seedlings growing in moist soils produced more root and shoot dry-weight than they did in dry soils (Awe, 1973). Awang (1977) showed that root growth of eucalypts seedlings was reduced by drought.

Studies have shown that the strong competition offered by weeds to the growth of many tree species derives from several factors. Weeds exhibit, when young, a rapidly spreading and deeply penetrating root system which gives them an early advantage in obtaining water and nutrients (Muzik, 1970) and they have the ability to extend roots into soil whose moisture content is at permanent wilting point (Sutton 1969). This results in a decrease of water available in the soil as there are a very much greater number of root tips per unit volume of soil on the weed root system than on that of the trees.

The species and/or provenances differences:

The differences between the two eucalypt species were evident in their dry weights. In the first experiment, the dry weights of the *E.camaldulensis* seedlings were greater than *E.grandis* mainly because of a greater shoot dry weights (Figure 4.6).

Within the species the provenances of *E.camaldulensis* differed: the Petford provenance tended to be bigger with greater dry weights than the provenance from Lake Albacutya. In *E.grandis,* the W. of Wandecla material was generally bigger than that from N. Coffs Harbour (Figure 4.6).

In the second experiment, the five provenances of *E.camaldulensis* had similar total dry weights but the components differed, especially the stem and roots dry-weights (Figure 4.11). The Lake Albacutya had the biggest stem dry weight but the smallest root dry weight (Figure 4.11). This is discussed further in the next section.

The provenances of *E.camaldulensis* tended to respond differently to the treatments: all provenances reduced their respective weights in presence of the weeds but Gilbert River and Victoria River reduced weight further when the low water regime was allied with the weeds (Figure 4.13). Moreover, on a low water regime in the presence of weeds, the Petford weighed more than the other provenances notwithstanding the fact that weed growth was high under the Petford provenance (Table 4.19). Therefore reduction in growth due to the effect of weeds and low water was less in this provenance than in the others.

Other authors have commented on dry matter production and the relationship to water stress condition. Myers and Landsberg (1989) observed that reduced dry matter production caused by prolonged water stress was less in the species from the arid environment (*E.brockwayi*) than in the moist habitat (*E.maculata*). Gibson *et al.* (1991) showed that water stress reduced the dry-weight of seedling shoots of Tennant Creek (semi-arid zone), Katherine (dry tropics) and Petford (wet tropics) provenances, but the effect was only significant in Tennant Creek seedlings (least variation was observed in Petford in relation to Katherine).

4.4.4. The partitioning of dry matter

The treatment effects:

In the second experiment the allocation of dry matter was odd. Both weeds and the low water regime affected the allocation of dry-matter to the different seedling components. Under these regimes the seedlings allocated more dry-matter to the stem and reduced accordingly the amount to roots. Consequently, the root:shoot ratio was reduced with the low water regime and even more so when weeds were present (Figure 4.9).

The root:shoot ratio was expected to increase with stress. Trees in arid environments partition more of their carbon below ground and thus a plant responds to soil moisture deficits by increasing the size of the root system thereby increasing surface area and absorptive capacity of the roots (Teskey and Hinckley, 1986; Eldridge and Cromer, 1987). Therefore, species with higher root:shoot ratio are better able to cope with dry sites than those with small ratios (Awang, 1977). Within a species, seedlings obtained from seeds of populations growing in more arid climates commonly have a greater root:shoot ratio (Pallardy, 1981). In an earlier study, Zimmer and Grose (1958) observed that eucalypts species typical of dry areas had a higher root:shoot ratios than those species from wetter areas. Parsons (1969 - cited by Bachelard, 1986) concluded that *E.socialis* may be better adapted to drier environments because of a higher root:shoot ratio.

Thus the general consensus is that the tendency to bigger root:shoot ratio by species from drier sites is a result of a greater development of their roots in search of water. The results of the glasshouse study show the reverse (lower root:shoot ratio). This may require further studies but other factors may be operating. The effect might be related to the pot size used in the experiment combined with severe competition with weeds in the same volume of soil. Also the limited soil volume of the pots would probably not have allowed seedlings to develop their full root system.

The species and /or provenances differences:

Though provenances did not differ in the amount of dry-matter allocated to leaves, as noted earlier, the Lake Albacutya allocated more biomass to the stem at the expenses of the roots whereas the other four provenances put more emphasis on their roots. Consequently, the root:shoot ratio was lowest in the Lake Albacutya (Figure 4.11).

Provenances also tended to differ in the way they allocated dry-matter to the different parts of the seedlings as a response to treatments (Figure 4.13):

(i) Treatments did not affect the root:shoot ratio of seedlings from Petford. This provenance increased the amount of biomass allocated to the roots in the low water regimes and, therefore, its root:shoot ratio tended to increase in the more stressed treatment (low water with weeds).

(ii) Manning Creek and Victoria River material markedly decreased their root:shoot ratio in the low water with weeds present. The Gilbert River material was affected by the low water regime regardless of the presence of weeds.

(iii) The root:shoot ratio of the Lake Albacutya decreased with weeds regardless of the water level regime.

Different species respond differently to competition. Differences in the early patterns of root system development may be particularly important in determining the competitive ability and therefore the success of species in an environment where competition is intense (Neave, 1987). For instance, in a glasshouse study in Canberra, seedlings of *Acacia holosericea* (from low rainfall areas) were more efficient at allocating photosynthate to root production, resulting in a bigger root:shoot ratio thus making it better able to withstand water stress through increasing water uptake (Gwaze, 1990).

Prasit (1979) founded no differences in the root:shoot ratios between provenances of *E.camaldulensis* from a wide range of native occurrence (he used provenances from North and South and from Lake Albacutya). However, Awe (1973) observed that although seedlings of the Katherine provenance had a greater total dry-weight on well watered treatments, the root:shoot ratio was greater in the drier treatments, indicating an ability to produce roots very rapidly to penetrate a poorly structured soil under sub-optimal moisture conditions. Similarly, Awang (1977) observed that root:shoot ratios of several eucalypts species were not significantly different under full moisture conditions but they differed in drought and shade treatments: for instance *E.pilularis* significantly reduced the ratio on the drought treatment, while *E.acmenimoides* increased the ratio and no significant changes were observed for *E.microcorys* and *E.saligna.*

It appears in the glasshouse experiment that the Lake Albacutya provenance put emphasis on development of the aerial parts rather than the roots. The lower root:shoot ratio observed on Lake Albacutya (a provenance from the temperate inland climatic zone) may suggest this provenance will be less able to cope with dryer sites than the northern provenances.

In contrast, the Northern provenances tended to allocate greater proportion of their assimilate to root growth and tended to increase root growth in treatments with grass and by doing so, they explored a larger volume of soil which enabled those provenances to cope with stress. As noted, Petford provenance (from the humid tropical highland) increased the root:shoot ratio in the low water regime and also when weed was present suggesting it may be better suited to weedy sites.

However, the Petford material from the humid tropics did produce a lower root:shoot ratio compared to the other three northern provenances (from the dry tropical inland climatic zone). Gibson *et al.* (n.d.), in a glasshouse experiment in Canberra, also found that seedlings from humid tropics had lower root:shoot ratio than seedlings from dry-tropics and semi-arid on the water stress treatment due to relative increases in root growth. This is consistent with the water regimes experiments here and indicates that Petford probably is not so dependent on its roots to search for water.

Recently, Gibson *et al.* (1991) showed that provenances of *E.camaldulensis* differed in physiological characteristics according to their climatic zones. These may be adaptations to the available moisture to them: The Petford and Mt.Carbine seedlings (from the humid tropics) adjusted to water limitation with changes in gas-exchange and became more water-use efficient by reducing stomatal conductance while increasing leaf transpiration efficiency, which meant these provenances were suited to environments where rainfall is unpredictable. They are able to capitalise on the recurring wetter periods. The Katherine and Lennard River seedlings (from the dry tropics) did not adjust to water stress by lowering stomatal conductance or CO_2 assimilation. They responded to water-limitation by changes in dry weight ratios and were less sensitive to water stress than Petford. Thus these provenances are better for the drier plantations. The Katherine and Lennard River seedlings increased root growth to cope with dry conditions. In contrast, the Tennant Creek and Mt.Isa seedlings (from semi-arid regions) adjusted to water limitation with changes in morphology, and become more sclerophyllous by suppressing apical growth, increasing root:shoot ratios and increasing the specific leaf weight and chlorophyll concentrations on the leaves. They are the most likely to resist dry periods successfully.

The ability of the Petford material to adjust stomatal conductance rather than having to make morphological changes would presumably make it better able to compete with the weeds and indeed other adverse water condition and yet to respond quickly when conditions improved. This provenance has a reputation for successful growth from a very wide range of trials (Eldridge, 1975). Results by Gibson *et al.* (1991, n.d.) indicate one possible reason for this and provide an explanation for the performance of this provenance in the glasshouse and field trials.

4.4.5. Allelopathy: a possible effect

Other effects also need to be considered. Root systems, can be limited in competition by the (i) release of toxic substances from roots or other organs associated with plants and the (ii) production of toxic substances during decomposition (Crafts and Robbins, 1962; Muzik, 1970; Del Moral and Muller, 1970; Yodzis, 1978; Chaney, 1981; Hollis *et al.*, 1982; May and Ash, 1990). Allelopathy is defined as the direct or indirect harmful effect by one plant on another through the production of chemical compounds that escape into the environment (Rice, 1985). It is possible therefore that allelopathic effects between the grass and the Eucalypts have occurred in these experiments.

The degree of impact of allelopathy and the concentration of allelochemicals is dependent not only on the amount of source material (Larson and Schwarz, 1980) but also on the soil water balance (Del Moral and Muller, 1970). In situations with low rainfall, insufficient to cause runoff or deep drainage, there will be a tendency to maximise allelochemical concentrations (May and Ash, 1990) and researchers have noted that plant response can vary with the amount or concentration of an allelopathic substance or extract (Larson and Schwarz, 1980). For instance, eucalypts fail to inhibit annual herbs on sand. The conditions for allelopathic interference were optimal on soils that were poorly drained, poorly aerated, shallow and high in coloidal content (Del Moral and Muller, 1970).

Allelochemicals can influence survival, root and shoot growth and dry-weight accumulation of seedlings in different stages of development (Larson and Schwarz, 1980; Rice, 1985). It was suggested by Hollis *et al.* (1982) that allelopathy can be important in the first stage of plant development as antecedent vegetation can exert allelopathic influences on subsequent successional processes. Abdul-Wahab and Rice (1967) found inhibition of seed germination and seedling growth of several species by Johnson grass (*Sorghum halepense* L.).

Ellis (1992) mentioned several experiments established on the highland forests of Tasmania (Australia) where the interaction of *E.delegatensis* and a grassy ground cover showed the importance of the mycorrhizal associations of the seedlings. Grassland soil itself was inhibitory to the growth of tree seedlings. When pots of grassland soil were inoculated with 10% of soil from an eucalypt stand, inhibition was removed completely: seedlings grew vigorously and the mycorrhizal formed were ectotrophic and similar to those formed in 100% eucalypt soil.

The hypothesis that allelopathic effects of weeds on Eucalypts seedlings could be interactive with different species and more importantly with different provenances should be examined further. Clearly it is important to study the relationship eucalypt trees have with weeds. Eucalypt plantations elsewhere have been established in grassland areas that have never before had this genus and allelopathic associations might be one factor in the strong effect exerted by grass upon the tree.

In summary, growth was reduced by weeds probably due to competition for water but possibly by allelopathy. The effects were variable between species and provenances. The two provenances of *E.grandis* only differed with soil type, where W. of Wandecla was taller than N. Coffs Harbour, whereas, provenances of *E.camaldulensis* differed in their response to treatments. A north-south differences was noted for several parameters as well as variation between the northern provenances.

The provenance from the humid tropics (Petford) was the least affected by adverse treatments whilst those from the dry tropics (Gilbert River, Victoria River and Manning Creek) were affected by the low water with weeds. The provenance from the temperate zone (Lake Albacutya) was most affected by the presence of weeds.

CHAPTER 5

General conclusions and recommendations

5.1. CONCLUSIONS

The importance of selection of *Eucalyptus* species and provenances for the specific conditions where they will grow was strongly evident in both the field and glasshouse studies reported in this thesis. Factors such as weed competition, soil type and water availability differentially affected growth of the species and their provenances.

The field study showed interactions with species and site treatment. For instance, the benefit of improving the operational environment through site preparation and weeding was effective in enhancing survival and growth of both *E.grandis* and *E.camaldulensis* but the level of requirement was different for each species. *E.grandis* performed better than *E.camaldulensis* on the mechanical site preparation with total weeding but not so when only partial weeding was applied.

A detrimental effect of weeds was noted in the field during the four years after planting. Survival and growth of *Eucalyptus* trees was significantly reduced with manual land preparation and a partial weeding regime. However, the trees did slowly compete successfully with weeds as they increased increment growth with time in this treatment.

The glasshouse studies have partially explained the field effects and re-emphasized the importance of correct selection of species and provenances for silvicultural treatments and the site conditions were they will be established. The experiments showed that species and provenances vary in the specific attributes that enable them to cope with stress environments. Weeds affected seedling growth in both *E.grandis* and *E.camaldulensis* by reducing their size (height, diameter and dry matter production), the number and size of their leaves and the number of auxiliary shoots. Growth of seedlings was also poorer on sandy soil and with the low water regime. Weeds and low water regime affected the allocation of dry matter within the seedlings of *E.camaldulensis*. (Unexpectedly, the overall root:shoot ratio was reduced with the low water regime and the effect increased in the presence of weeds).

Water availability appears to be the most important factor controlling the growth of the seedlings. It was presumed in the glasshouse experiments the presence of weeds increased the stress conditions of the seedlings as a result of water competition. However, it is possible allelopathic effects may also have occurred and these merit further study.

Variation between provenances was extremely important and could be related to the environmental conditions of their natural origin. The material from the temperate region (Lake Albacutya) emphasised development of aerial parts to the detriment of root growth. Its root:shoot ratio decreased in presence of weeds. It appeared this provenance was least able to cope with water stress and weeds. The three provenances from the dry tropics had the greatest root:shoot ratio of all provenances but they may be less able to cope with water stress as they also had decreased ratio in the low water regime with weeds. The provenance from the humid tropic (Petford) is well known as a good performer in numerous countries and hence in a wide range of environments. In these studies it showed an adaptability to tolerate stress and did not need to produce morphological adaptations to cope with dry and weedy conditions. Gibson *et al.*'s (1991) findings have indicated that this provenance possesses stomatal conductance characteristics enabling it to adjust to water limitation yet capitalizing on recurring wetter periods (either rain, overnight rehydration or other forms of precipitation). This would enable the provenance to tolerate a range of different environment conditions including sites with heavy weed growth.

E.grandis needs good land preparation and to be free of weed competition to perform well. The high mortality observed in the field and the reduced growth when in competition with weeds may be due to the amount of foliage that it produces allied with the smaller roots compared with the other species. Therefore to guarantee success when planting this species a bigger investment in site preparation and silviculture is required in comparison to *E.camaldulensis*.

5.2. RECOMMENDATIONS

It is well known that the correct selection of *Eucalyptus* species and/or provenances in plantations is important. These selection programmes should incorporate specific site types and site amelioration programmes and should be complemented by silvicultural practices operative for at least four years.

Poynton (1984) considered "cheap and easy to establish" as one of the characteristics to consider when selecting trees for firewood production. The Petford provenance has shown evidence of good performance in a range of environments - where soil, weeds, water availability and site preparation and maintenance interact. Because of its "plasticity", there is more certainty that it will succeed in plantation programmes even where there is no previous knowledge of performance. Species or provenances exhibiting similar plasticity should be sought.

Nevertheless, on much of the material the negative effect of weeds was strong. Whether weeds are competing for water or other factors are involved in the relations of plants x weeds should be studied in detail but necessarily on a provenance or seed source basis. Further studies comparing transpiration rates and water status of the seedlings and trees under weed competition are recommended. Additionally, studies are needed on the allelopathic effects of weeds upon the trees, or vice versa, during the first stage of development of the trees and on the possible effects that weeds can exert.

These series of studies have shown that glasshouse studies can help in understanding the behaviour of trees under different conditions of soil, water and weed competition. Such studies could be useful for screening species and provenances to find if others with the wide adaptability of *E.camaldulensis* from Petford do exist.

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APPENDIX I

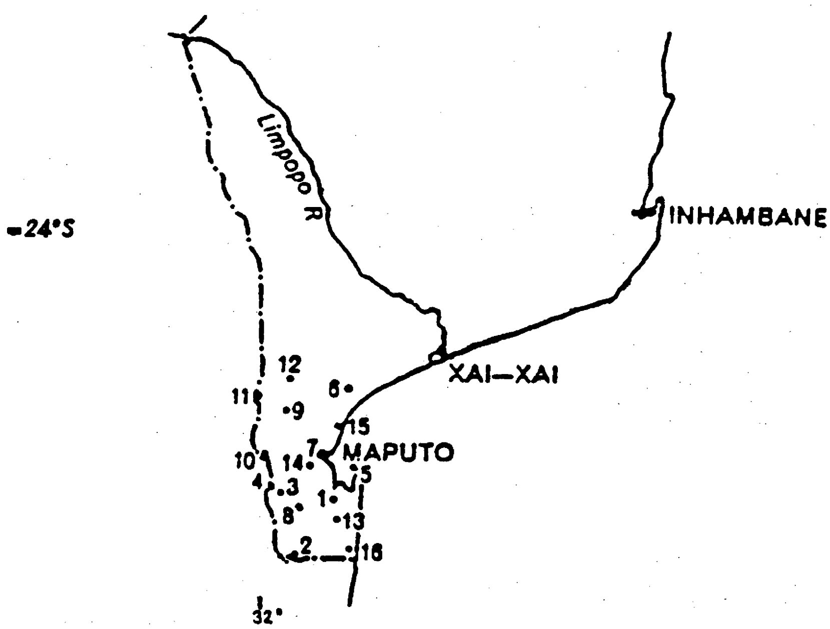
TABLE I.1: **Climatological data of some stations located in the study region: means over 20 to 31 years.**

STATION	LOCALIZATION	P (mm)	T -mean (ºC)	T -max. (ºC)	T -min. (ºC)	ET (mm)	HR (%)
Marracuene	25.44 S Lat. 32.41 E Long. 26 m Alt.	758.2	23.2	28.9	17.5	1391.9	70.0
Zitundo	26.45 S Lat. 32.50 E Long. 71 m Alt.	957.0	22.1	27.2	17.0	1251.0	74.0
Maputo	25.53 S Lat. 32.36 E Long. 60 m Alt.	783.7	22.8	27.4	18.3	1334.7	72.2
Mazeminhana	26.27 S Lat. 32.15 E Long. 61 m Alt.	595.1	22.5	29.6	15.4	1327.6	71.8
Umbeluzi	26.03 S Lat. 32.23 E Long. 12 m Alt.	714.6	22.8	26.5	17.8		68.0
Moamba	25.36 S Lat. 32.14 E Long. 100 m Alt.	587.3	23.9	27.4		1326.3	61.0
Namaacha	25.57 S Lat. 32.04 E Long. 594 m Alt.	894.8	21.1	23.8			
Mean		755.8	22.9	28.3	17.1		69.5

Source: Kassam *et al.*, (1981).

APPENDIX I (cont.)

FIGURE I.1: Location of some metereological stations in the region.



07..... Maputo
08..... Mazeminhana
09..... Moamba
10..... Namaacha
14..... Umbeluzi
15..... Marracuene
16..... Zitundo

TABLE II.1: Forecast woodfuel biomass balance for Maputo Province based on the existing stock in 1980 (Malleux, 1980) and using the assumptions defined on the next page.

YEAR	TOTAL NEEDS (million cum)	NATIVE FOREST		PLANTATIONS		TOTAL AVAILABLE VOLUME (million cum)	BALANCE (million cum)	% OF INITIAL EXISTING BIOMASS
		TOTAL EXISTING BIOMASS (million cum)	GROWING STOCK (million cum)	AREA (ha)	VOLUME (million cum)			
1980	0.98	36.46	1.20	*	*	1.20	0.22	100.0
1981	1.01	36.68	1.21	*	*	1.21	0.20	100.6
1982	1.05	36.88	1.22	*	*	1.22	0.16	101.1
1983	1.12	37.04	1.22	*	*	1.22	0.10	101.6
1984	1.18	37.14	1.23	*	*	1.22	0.04	101.9
1985	1.27	37.18	1.23	*	*	1.23	-0.04	102.0
1986	1.32	37.14	1.23	*	*	1.22	-0.09	101.9
1987	1.37	37.05	1.22	*	*	1.22	-0.15	101.6
1988	1.48	36.91	1.22	*	*	1.22	-0.26	101.2
1989	1.49	36.65	1.21	*	*	1.21	-0.28	100.5
1990	1.60	36.37	1.20	1588	0.19	1.39	-0.21	99.8
1991	1.65	36.16	1.19	253	0.03	1.22	-0.43	99.2
1992	1.70	35.74	1.18	418	0.05	1.23	-0.47	98.0
1993	1.80	35.27	1.16	331	0.04	1.20	-0.60	96.7
1994	1.88	34.67	1.14	182	0.02	1.16	-0.71	95.1
1995	1.96	33.96	1.12	263	0.03	1.15	-0.81	93.1
1996	2.02	33.15	1.09	312	0.04	1.13	-0.89	90.9
1997	2.14	32.20	1.06	410	0.05	1.11	-1.02	88.5
1998	2.25	31.23	1.03	180	0.02	1.05	-1.20	85.7
1999	2.36	30.03	0.99	150	0.02	1.01	-1.35	82.4
2000	2.45	28.68	0.95	1738	0.21	1.15	-1.29	78.7
2001	2.52	27.39	0.90	403	0.05	0.95	-1.57	75.1
2002	2.60	25.82	0.85					70.8

ASSUMPTIONS :

1.- Population growth and fuelwood consumption :

. Rural population growth : 2.3% / year
. Rural wood consuption : 1 m / inhabitant / year
. Urban population growth : - until 1990 : 8% / year
- to 2005 : 5% / year
. Urban wood consumption : 0.7 m / inhabitant / year
. Industrial wood consumption : 170 000 m - 600 000 m / year
(minimal capacity - full capacity)

CALCULATIONS :

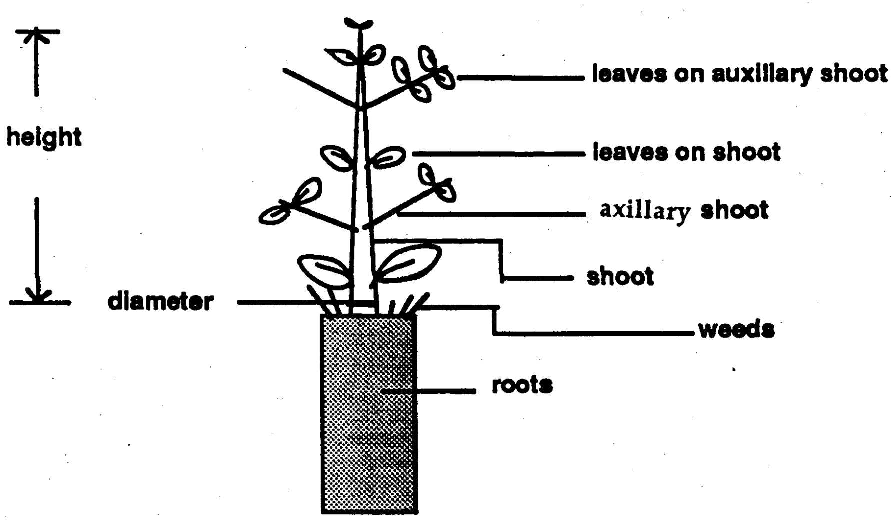
. Annual increment of native forests = 3.3% of the total existing stock .
. Volume of plantations = area X 120 m /ha .
. Total available volume = increment of native forests + volume of plantations .
. Balance = total available volume - needs .
. Adjusted total existing biomass of native forests = previous existing biomass + balance .

NOTES :

. Volume available after year 2002 will depend on the new plantations to be stablished from year 1992 , both in rural and urban areas .
. Negative balance values means an extraction above the annual increment .

APPENDIX III

FIGURE III.1: The diagram of the variables measured.



APPENDIX IV

TABLE IV.1: Analysis of variance showing the main effects and interactions , being significant at 5% level (*) ,1% level (**), 0.1% level (***) and not significant (n.s.).

VARIABLE	SIGNIF. TERMS	d.f	M.S.	VR
1.-Eucalyptus				
HEIGHT	treatment	3	513.1	9.02***
	provenance	4	917.35	33.49***
	treatm x proven	12	34.87	1.27 n.s.
	residual	48	27.39	
Ln DIAMETER	treatment	3	0.0609	10.26***
	provenance	4	0.0738	10.69***
	treatm x proven	12	0.0055	0.80 n.s.
	residual	48	0.0069	
Ln DROPPED LEAVES	treatment	3	0.4723	8.21***
	provenance	4	0.0496	1.55 n.s.
	treatm x proven	12	0.0202	0.63 n.s.
	residual	48	0.0321	
LENGTH OF LEAVES	treatment	3	78.68	30.95***
	provenance	4	19.643	9.51***
	treatm x proven	12	4.648	2.25*
	residual	47(1)	2.065	
WIDTH OF LEAVES	treatment	3	2.7742	8.32***
	provenance	4	1.5929	7.29***
	treatm x proven	12	0.1599	0.73 n.s.
	residual	47(1)	0.2185	
Ln No.TOTAL LEAVES	treatment	3	0.4367	7.04***
	provenance	4	0.4099	10.86***
	treatm x proven	12	0.0236	0.62 n.s.
	residual	48	0.0377	
DRY-WGT OF EUC.LEAVES	treatment	3	6.2196	14.88***
	provenance	4	0.3228	1.19 n.s.
	treatm x proven	12	0.1498	0.55 n.s.
	residual	48	0.2716	
DRY-WGT OF EUC.STEM	treatment	3	0.7371	10.01***
	provenance	4	0.6388	16.96***
	treatm x proven	12	0.0256	0.68 n.s.
	residual	48	0.0377	
DRY-WGT OF EUC.ROOTS	treatment	3	9.1934	14.14***
	provenance	4	0.8056	1.90 n.s.
	treatm x proven	12	0.3578	0.84 n.s.
	residual	48	0.4241	
TOTAL DRY-WGT	treatment	3	39.708	18.85***
	provenance	4	0.806	0.66 n.s.
	treatm x proven	12	0.519	0.43 n.s.
	residual	48	1.221	
ROOT:SHOOT RATIO	treatment	3	0.1022	3.32*
	provenance	4	0.1652	4.46**
	treatm x proven	12	0.049	1.32 n.s.
	residual	48	0.037	

APPENDIX IV (cont.)

VARIABLE	SIGNIF. TERMS	d.f	M.S.	VR
LEAF:TOTAL RATIO	treatment	3	0.0041	1.46 n.s.
	provenance	4	0.0024	1.26 n.s.
	treatm x proven	12	0.0027	1.38 n.s.
	residual	48	0.0019	
STEM:TOTAL RATIO	treatment	3	0.0016	4.32**
	provenance	4	0.0199	24.34***
	treatm x proven	12	0.0007	0.87 n.s.
	residual	48	0.0008	
ROOT:TOTAL RATIO	treatment	3	0.0081	2.91*
	provenance	4	0.0163	5.37**
	treatm x proven	12	0.0045	1.48 n.s.
	residual	48	0.003	
2. Weeds				
DRY-WGT WEED LEAVES	treatment	3	35.568	538.45*
	provenance	4	0.05	1.19 n.s.
	treatm x proven	12	0.0376	0.86 n.s.
	residual	48	0.042	
DRY-WGT WEED ROOTS	treatment	3	80.706	292.77**
	provenance	4	0.167	1.07 n.s.
	treatm x proven	12	0.083	0.53 n.s.
	residual	48	0.156	
TOTAL DRY-WGT WEEDS	treatment	3	223.4	387.34***
	provenance	4	0.397	1.33 n.s.
	treatm x proven	12	0.162	0.54 n.s.
	residual	48	0.299	

NOTE:- The critical F values were :

- for treatments : F 3,48 d.f. = 2.48 ; 4.31 ; 6.59 at 5%,1% and 0.1% level
- for provenances: F4,48 d.f. = 2.61 ; 3.83 ; 5.70 at 5%,1% and 0.1% level
- for treat x prov : F12,48 d.f. =2.00 ; 2.66 ; 3.64 at 5%, 1% and 0.1% level.